MODELLING REGIONAL FOREST INDUSTRY DEVELOPMENT IN NEW ZEALAND

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pocket

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ABSTRACT

Planning to link resources, production and markets for the forest sector is characterised by diverse and scattered elements which need to be analysed over long time spans. A wood processing planning model (WPPM), emphasising primary processing at the regional level, has been developed as part of an ongoing programme of forest sector modelling research. The need for such an approach is apparent in the New Zealand industry, where the benefits of formal and end-directed sector planning could be very substantial, particularly in view of the imminent increases in wood supplies.

Existing models and modelling efforts in New Zealand and worldwide have not, in general, addressed the specific problems of forest industry strategic planning. They do not adopt an integrated approach to using and growing the resource. Models which incorporate considerations of processing are often over-generalised, or restricted in the time dimension, thus reducing their utility in strategic planning applications.

WPPM is formulated as a mixed integer linear program for optimising regional economic benefits from wood processing, with constraints on resource inputs, productive capacities, markets and capital availability, amongst others. Capacity changes are restricted to discrete step sizes in the model, a feature adding to its realism and found in few other applications. Model size is determined by the objective(s) of the user; WPPM can cater for all planning levels from single mills to regional sector analysis.

The model structure, function and capability are outlined using a sectoral analysis of the Canterbury region as an example. The results of this analysis, although indicative only, provide insights into likely industrial development which would benefit the region, along with a wealth of information on future "optimal" production levels and sales. The results for the initial planning periods of this case study (1988 and 1989) are compared with the actual state of the regional industry in this period, allowing a limited verification of the modelling system. While these results show that the model captures the dynamics of the region's wood processing sector well, full verification of WPPM will require more extensive use and testing over a range of different objectives.

CHAPTER 1

INTRODUCTION

What we anticipate seldom occurs; what we least expect generally happens.

Disraeli

The timelessness of the above warning, issued more than a century ago, is evident in the current state of the New Zealand forestry sector. Few in the sector in 1985 (when this study commenced) would have predicted the tumultuous events of the last 3 years: the floating of the New Zealand dollar, the demise of the State Forest Service, the introduction of a new, more restrictive, forestry taxation regime, and the corporatisation and now privatisation of the State exotic forests. These unanticipated developments, together with the failure of export markets for the country's main timber species, radiata pine, to materialise as expected, have led to some grim statistics: from 1986 to 1988, nearly one sawmill per week ceased operations (Hawkins, 1988a).

One thing that the New Zealand forest industry can be relatively sure of is that the raw material available to it will increase greatly over the next two decades. But major planning decisions need to be made now if this expanding resource is to be used to yield the greatest net return to the country as a whole. The research reported in this thesis provides a form of planning for the utilisation of New Zealand's radiata pine crops at the regional level, planning that is urgently required if economic recovery and fuller employment in gainful manufacturing is to materialise.

1.1 Objectives and Scope

Many analyses of the New Zealand wood supply situation have been carried out over the past two decades (e.g. Familton, 1969; Hosking, 1972; Levack, 1977; Elliot and Levack, 1981; Butler *et al.*, 1985; Collins *et al.*, 1988). Most of these analyses gave rise to wood supply models and a corresponding recognition of the need for some form of national planning in the forest sector. It is only relatively recently, however, that the need for broadening the scope of such analyses to include marketing, processing, infra-structural consequences and other non-supply factors has been recognised. The Development Finance Corporation (D.F.C.) heralded this shift in emphasis in its "Forest Industry Study" (D.F.C., 1980), calling for a more holistic and coordinated approach to planning within the New Zealand forest sector.

Despite advances in forest sector planning since 1980, gaps remain in our understanding of the interactions between wood growers, processers and markets, at both the regional and national level. The forestry sector has the potential to become a major part of the New Zealand economy, generating up to 10 per cent of Gross Domestic Product, some 30 000 direct jobs, and billions of dollars in export earnings (Tapsell, 1989). It is therefore essential that interactions within the sector itself, and with other sectors of the economy, are adequately understood for coordinated strategic planning of the sector's development. Paradoxically, the component of the sector which will be responsible for generating the economic benefits from New Zealand's forests (the wood processing industry) is also the least studied. The need for, and importance of, modern, efficient processing plants in New Zealand's forest sector development is almost universally recognised: a recent Minister of Finance stated that the country's forests represent only 3 per cent of the potential income attainable from their wood, with the remaining 97 per cent to arise from development of the wood processing industry (Douglas, 1988). However, there has been little research carried out into the mechanisms of planning for such development. The overall aim of this study is to produce a tool to aid strategic planning and decision making carried out by and for the New Zealand wood processing industry.

Specifically, the objective of this research is to develop a methodology for characterising and strategically analysing a range of possible processing options for utilising industrial roundwood in a region. The characterisation and analysis will be in sufficient detail to allow individual processors to be cognisant of the resources available to them and to rationalise their use of these in terms of likely market prospects. The proposed methodology should:

(1) coordinate such factors as forest resources, forecasted market demands for forest products, existing and potential processing capability, processing productivity, and infrastructural consequences, while emphasising processing;

(2) deal specifically with processing options for the Canterbury region, while serving as a prototype which could be applied to any region of New Zealand;

(3) be compatible with the structure of previous forest sector modelling work carried out at Canterbury; and

(4) be realistic and usable in practice.

Attainment of these objectives should result in a means of modelling the interfaces between wood supply schedules and wood processing at a regional level in order to facilitate rational planning and coordination of the two components.

Although the methodology developed here serves as a prototype for other regions of New Zealand, the primary focus is on Canterbury's forest processing industry. This is largely due to logistic considerations with respect to data collection, with the study base and computing facilities located at Canterbury. This limitation does not decrease the utility of the resulting model; however, considerably more emphasis is placed on the analysis of feasible processing options within the region than on others outside it.

The term "wood processing industry", as used here, refers to primary processors of exotic softwood plantation species (principally radiata pine). The methodology does not consider secondary wood processing (treatment, furniture, joinery, *et cetera*). Inclusion of secondary processing would require a careful analysis of the relevant industries, simply beyond the scope and resources of this study.

Since the research emphasis is on the primary processing industry, no attempt is made to develop new forest growth or market models. Existing models and data bases are utilised and modified as necessary to provide input data for the processing model. Resources and demands are dis-aggregated where necessary to match the model structure. Note, however, that other model users can use any data sources available to them.

Although the resulting model could be used for strategic planning at an individual mill level (see part 1.2), its most valuable role is seen in regional sector planning for wood processing. Much of the description of the model structure, and the case study illustrating its use, assume such a sectoral application.

Finally, the methodology, although incorporating economic data, is not a true econometric model of the wood processing industry. Insufficient data are available (particularly with respect to processing costs and dis-aggregated trade statistics) to allow construction of such a model. While an econometric approach would require a separate model for each region of the country, the approach taken here allows analysis of any region using a consistent structural framework.

1.2 Potential Users

There are a number of potential uses and hence users of a tool for aiding strategic planning in the wood processing industry. The most obvious user is the industry itself, which is ultimately responsible for its own development and profitability. Users could range from individual mills or groups of mills interested primarily in log allocation, to industry associations (such as the New Zealand Timber Industry Federation) attempting to help members coordinate marketing and development. Application of the tool to individual mill log allocation planning would require fairly frequent updating runs. Due to the computer requirements of such a tool, it is unlikely that any but the largest processors would use it regularly on an individual basis. However, forest industry consultants could alleviate this, using the model to assist clients in log allocation planning or one-off strategic development decisions.

Forest growers could also make use of such a tool. Since most of New Zealand's State-owned exotic forests will soon be sold to processors, the distinction between growers and users of wood will lessen. Regardless of who grows forests, however, a knowledge of likely industry structure and processing options on a regional level would be invaluable for planning silvicultural operations and marketing of logs.

The last type of user identified is that most likely to use the tool for sectoral analyses. Government bodies and agencies, either at a national (e.g. Ministry of Forestry - MOF, Treasury) or local (e.g. United Council) level, could use the tool to identify feasible regional processing options, to evaluate (or attract) proposals for expansion of existing or construction of new processing facilities, and for planning regional economic development. Use of the tool at a sectoral level should involve updates at an interval of one to three years, to ensure changes in market forecasts, processing costs, *et cetera* are incorporated in the regional sector plan. As stated above, the major contribution of the tool lies in such use.

1.3 Thesis Structure

The remaining chapters of this thesis document the development and use of a regional strategic planning model for wood processing. Chapter 2 reviews the current New Zealand forest sector and the range of planning models available to it. Strategic planning is defined, followed by a comprehensive review of worldwide forest sector strategic planning models and the observed gaps with respect to wood processing. Chapter 3 documents the mathematical structure of the wood processing planning model developed here, while the following two chapters are devoted to model data requirements (Chapter 4) and documentation of the computer programs making up the model system (Chapter 5). A case study of the Canterbury region is presented in Chapter 6, demonstrating the function and capability of the modelling system. Chapter 7 provides an evaluation of the model, in terms of computer requirements and the case study results, and recommends several considerations for future development of the system. The final chapter summarises the results of the research and the conclusions drawn from them.

CHAPTER 2

FORESTRY PLANNING: NEEDS AND MODELS

Planning in forestry has evolved along with the changing needs, priorities and objectives of both public and private forest owners. Since the prime needs of most early forest owners were to ensure continuity in the supply of forest goods (e.g. timber, wildlife, etc.), forest planning traditionally evolved in the face of impending timber shortages that threatened such supplies. The rigorous European approaches to regulating timber yields, epitomised by the optimal rotation model of Faustman (1849), were the result of fears of inadequate future supplies. In the words of Heinrich Cotta, a German forester who published his "Advice on Silviculture" in 1816: "We have now a forestry science because we have a dearth of wood" (quoted in Baker, 1950).

The early silviculture and planning models developed in Europe were exported to the new world, with some countries (e.g. Brazil) still employing them widely today. However, the extensive nature of forestry in most colonies led to departures from the classical European methods and their emphasis on the normal forest. In the United States and Canada, for example, widespread fires at the turn of the century made it clear to the nascent government forestry bodies in both countries that large-scale fire management and planning procedures were necessary before more intensive tending of trees and stands could become possible (Davis and Johnson, 1987).

In New Zealand, one of the earliest formal forest planning exercises was undertaken in the early 1920's by MacIntosh Ellis, the inaugural Director of the country's newly founded Forest Service. Ellis analysed yields from existing indigenous forests of the day in the face of widespread concern over their depletion, together with the potential for introduced species to supplement these yields. He concluded that existing supplies of indigenous softwood timber would be depleted by the mid 1960's. To avoid such a situation, Ellis recommended that the 25 000 hectares of state exotic softwood plantations then in existence should be increased to at least 125 000 hectares within 10 years if New Zealand was to remain self sufficient in timber, and so provide the wood necessary for its "progress and future prosperity" (Ellis, 1925). His goal was reached well ahead of time, with the establishment of the first major New Zealand exotic softwood plantations on the pumice plateau of the central North Island. The private sector, encouraged by this enthusiasm, kept pace, resulting in a total exotic plantation resource of almost 250 000 hectares by 1931. Ellis' vision, described as having a stronger strategic base than subsequent efforts to expand New Zealand's plantation resource (Sutton, 1978), has led the country not only to self sufficiency in wood, but to the potential for substantial export earnings as well.

The first part of this chapter outlines the subsequent development of New Zealand's forest sector, summarising the evolution of forestry planning models from this original perspective. As in many countries, a changing emphasis on markets and an increasing complexity of potential processing options have given rise to a requirement for more comprehensive forest planning models than the early yield regulation models. This need can be met at least partly through the development of forest sector strategic planning models. The second part of this chapter defines the concept of strategic planning and reviews the current range of forest sector strategic planning models available; assessments of overseas as well as domestic models are included.

2.1 Forest Planning in New Zealand

2.1.1 The forest sector in New Zealand

The New Zealand forest sector has, over the past three decades, become increasingly reliant on its exotic softwood plantations, composed principally (89 per cent) of radiata pine (*Pinus radiata* D.Don.). While these plantations occupy only 4 per cent of New Zealand's land area of 27 million hectares, they account for more than 94 per cent of the country's roundwood production (MOF, 1988a). The reliance on exotic plantations will increase over the next few decades, as increasing areas of indigenous forest are taken out of production for protection, nature and wilderness reserves.

Table 2-1 summarises the trends in area and production for native and exotic forests over a 100 year period. The future estimates for exotic production are based on forecasts assuming an average afforestation rate of 20 000 hectares per year from 1987 to 2000 (Burrows *et al.*, 1987a). This afforestation rate, a 60 per cent reduction from the average level of the previous five years, was judged to be the most likely response to a new "neutral" forestry taxation system introduced in early 1987 and the concurrent corporatisation of the state forests. This assumption appears somewhat optimistic, with new planting for 1988 at just over 17 000 hectares (Forest Owner's Association, 1988). However, even if new forest plantings drop more dramatically (forecasts of new planting rates falling below 6 000 hectares per annum in the early 1990's have been reported by Hall, 1988), annual recoverable volumes will still increase to at least 25 million m^3 by 2020, based on the current 1.15 million hectare exotic resource. While the area of native forest will also increase (by almost 10 per cent) over this period due to new planting and restoration of natural high forest from scrubland, indigenous timber production will actually fall to about two-thirds of current levels as the non-timber values of these forests continue to gain precedence. However, the low levels of increasingly valuable indigenous timbers produced should still be able to sustain a small scale, high value added industry (MOF, 1988b).

Table 2-1. New Zealand's forest estate.

Year	Area (000 ha) Native	Exotic	Roundwood production (MMm3) Native	Exotic
1920	6 000	75	1.4	0.1
1940	6 000	327	1.4	0.3
1960	6 200	350	1.7	3.0
1980	6 200	850	0.6	9.4
2000	6 300[1]	1 300	0.4	17.7
2020	6 400	1 300	0.4	29.5

Note: 1. Future area and production figures for native forests are estimates, based on current government policy regarding these forests.
Sources: Burrows *et al.*, 1987a; Collins *et al.*, 1988; MOF, 1988a; 1988b.

The striking increase in production from exotic forests by the turn of the century is a direct result of an extensive planting boom during the 1960's and 70's. This second planting boom (following the first, as described above, by four decades) saw New Zealand's exotic forest estate grow by over 500 000 hectares. This rapid growth was brought about by the following combination of factors:

(i) a 1960 review by the New Zealand Forest Service (NZFS) showing a domestic supply deficit by the turn of the century;

(ii) government grants and loans (from 1962) to land-owners who planted trees;

(iii) Forestry Development Conferences in 1969 and 1974, emphasising the economic viability of plantation forestry;

(iv) a strong Japanese log market.

There are several contrasts between the resulting "new" crop that was established from the 1960's onwards and the "old" crop planted in the 1920's; these contrasts are summarised in Table 2-2. The old crop resource should be almost completely cut out by 1990, with the intensively managed, export oriented transition and new crops taking its place. This will likely require major changes in both the processing and marketing of New Zealand timber, with the need for export market development a priority.

Export values of New Zealand wood products have undergone a dramatic 14-fold increase since 1970, with almost $1,000 million of forest based exports reported for the year ended June 30 1988. Table 2-3 provides a breakdown of total export value by major products for the past 18 years. Exports of forest products currently earn about 10 per cent of New Zealand's total overseas revenues, consuming half of its roundwood resource (4.8 million m^3) in the process. By 2020, when volumes in roundwood equivalent available for export should be about 15 million m^3 per year, forest exports could, according to one analysis (Stoddart, 1988), increase by up to $3,200 million, accounting for up to 20 per cent of total annual overseas earnings. Such an increase would add over $4,000 million to the domestic economy, increasing gross domestic product by nine per cent and creating 38 000 direct jobs. Such expansion will be possible only with coordinated long range planning for the sector as a whole, and will require a commitment from government to keep interest rates, inflation and exchange rates low. As this commitment appears to be forthcoming from the current Labour government (Rankin, 1988), the onus is now on the sector to plan and implement its expansion.

Table 2-2. Contrasts between new and old crop resource.

New crop	Old crop
-wide geographic spread	-mainly Bay of Plenty and Waikato regions
-steep country, high costs	-relatively gentle terrain
-more than 90% Pinus radiata	-60% Pinus radiata, with Douglas-fir, Corsican, ponderosa and lodge pole pines
-intensively managed (pruned up to 6 m, thinned to 200-370 stems per hectare by age 12)	-silviculturally untended (or belatedly tended with few quality improvements)
-average rotation 25-30 years (mean dbhob 50 cm)	-average rotation 45-50 years (mean dbhob 65 cm)
-average density 400 kg/m^3, lower strength/stiffness[1]	-average density 425 kg/m^3, higher strength/stiffness[1]
-genetic gains in wood quality through improved planting stock	-unimproved planting stock
-established with export markets in mind	-established to meet domestic demand

Note: 1. Walford (1982) predicts that strength and stiffness of new crop sawntimber will be at least 10 per cent lower than that sawn from the old crop, although this may be alleviated by the use of genetically improved planting stock (e.g. NZFS, 1985b).

The New Zealand forest industry presently consists of 400 sawmills, six plywood and veneer plants, eight pulp and/or paper mills, three particleboard mills and four fibreboard plants (MOF, 1988b). Table 2-3 shows that export earnings have been increasing markedly in the pulp, paper and other (primarily reconstituted wood products) categories, while roundwood and sawntimber exports have grown more slowly (apart from the jump of almost 100 per cent in the value of logs and poles exported from 1987 to 1988, explained by a large shipment of poles to Korea). Although roundwood exports (particularly to the highly capitalised manufacturing industries of Japan and Korea) will continue to play an important role in New Zealand trade statistics, these figures illustrate the trend to add value to export products via domestic processing.

This trend, coupled with the dramatic increase in wood supplies over the next 30 years, implies that a corresponding expansion of the wood processing and marketing sectors must occur if New Zealand hopes to reap full rewards from its intensive forestry efforts. An indication of the magnitude of the expansion required was given by Stoddart (1988), who stated that the upcoming 15 million m^3 increase in log supplies could support four new ply mills, 28 new saw mills, five new reconstituted board mills, six new paper mills and a bleached kraft paper mill. The models reviewed in the following section have been developed over the past 20 years to assist in planning the unprecedented expansion facing the New Zealand forest sector.

Table 2-3. Export values ($NZ million FOB) of major forest products.

Year ending June 30:	Wood-chips	Logs/ poles	Sawn-timber	Wood pulp	Paper/ P.board	Other[1]	Total
1970	1.0	24.1	10.0	7.2	20.4	3.8	66.5
1975	5.6	17.6	10.5	43.6	35.9	5.8	119.0
1980	13.1	62.1	64.8	120.2	124.1	61.4	445.7
1981	20.1	49.4	87.2	151.3	153.0	71.8	532.8
1982	23.1	28.9	79.7	155.7	182.8	80.7	550.9
1983	27.0	28.3	72.4	161.3	134.4	79.0	502.4
1984	30.5	39.5	89.0	190.2	191.1	110.7	651.0
1985	45.0	37.2	126.3	202.7	236.5	148.3	796.0
1986	43.6	40.6	111.4	219.8	187.5	165.1	768.0
1987	43.6	41.9	93.7	252.9	176.9	177.3	786.3
1988	35.9	80.6	113.9	353.6	200.1	201.6	985.7

Note: 1.Other products are fibreboard, particleboard, plywood, veneer, manufactures of paper and paperboard, and miscellaneous forest products.
Sources: Department of Statistics (1970-84); NZFS (1970-84); MOF, 1988a.

2.1.2 Planning models in New Zealand - an overview

The term "planning model" refers to any decision-making aid, ranging in complexity from the toss of a coin to sophisticated computer based models. The range of recent applications of planning models in forestry is impressive. Harvest scheduling, fire-fighting, tree breeding and log bucking problems (to name just a few) have all been tackled successfully using computer planning models based on operations research techniques. The types of planning models reviewed here are all computer based and can be ranked according to the hierarchy shown in Figure 2-1. The evolution of forest planning models has conformed with this hierarchy in many parts of the world, and New Zealand is no exception. The following review focusses briefly on the lower components of the hierarchy, with sectoral planning models discussed in detail in part 2.2.

Tree and stand growth models. One of the earliest forest planning needs, as discussed in the introduction to this chapter, was for the regulation of forest yields. Predictions of future growth of tree crops are essential for such regulation to be effective. Models for this purpose can be conveniently grouped into those dealing with natural forests (even and uneven aged) and those dealing with plantations (managed or unmanaged - Clutter *et al.*, 1983). Within this grouping, models can be classified (after Munro, 1974) as stand level (requiring only stand statistics as input), distance independent tree level (requiring tree statistics as input), and distance dependent tree level (requiring tree or stand diameter statistics plus spatial distribution of trees as input). Bruce and Wensell (1987) proposed a new standard for growth model classification, distinguishing between models designed for irregular stands (generally uneven aged with relatively high variability in stand statistics) and those for regular stands (generally even aged with relatively low variability in stand statistics). Their classification also recognised the differences between process models of tree growth (biological or botanical) and empirical models (those traditionally used by forest managers).

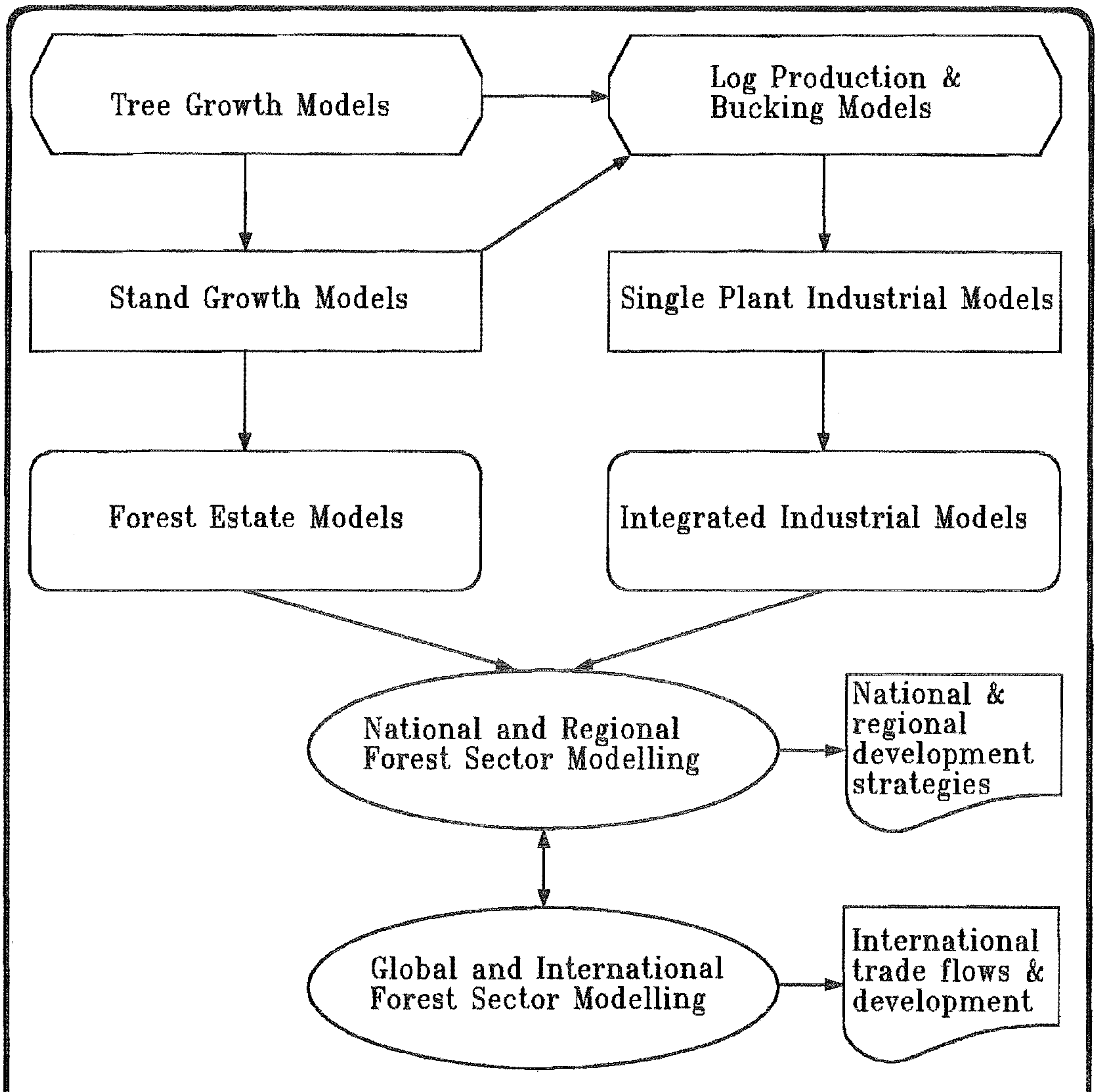

Figure 2-1. Hierarchy of forest planning models.

Goulding (1986) has reviewed the development of the current range of New Zealand growth and yield models for radiata pine. All of these are empirical stand level models, designed for regular forests. Regardless of their particular emphasis or classification, most empirical growth and yield models provide predictions of the development of height, volume and density (number of stems) over time. Such predictions assist decisions regarding optimal harvest ages, planting densities and timing of management activities (e.g. thinning) on a stand level. More importantly, growth models can be used as inputs to models for managing entire forests, as discussed next.

Forest estate models. Growth and yield models are restricted to modelling tree or, at most, stand growth. A forest, however, consists of many different stands, each usually having individual characteristics of growth, accessibility, management intensity, *et cetera*. Extending the optimal management strategies for single stands derived from a stand level growth model to an entire forest is therefore rarely optimal for the forest as a whole. The need to plan for aggregates of non-uniform forest stands gave rise to the concept of forest estate modelling. Such models incorporate inputs from relevant growth models in some form, as well as recognising other distinguishing stand features.

RMS-87 (Resource Maturity Simulator - Allison, 1987), IFS (Interactive Forest Simulator - Garcia, 1981) and FOLPI (Forestry Oriented Linear Programming Interpreter - Garcia, 1984) are the most widely used forest estate models in New Zealand. Both RMS-87 and IFS are simulation models, allowing the examination of different management alternatives for a given forest. In both, the forest is described in terms of crop types (groups of stands with similar yield, management, accessibility, location, ownership, *et cetera*). The state of the forest in a given period is defined by the area in each age class within each crop type. For each period of the simulation, areas may be harvested, planted or otherwise treated, yielding values or volumes as defined by user supplied tables (volumes for individual crop types can be input from the appropriate growth and yield models). The user specifies the management actions to be followed each period and can produce a number of reports at the end of the simulation describing the results of those actions.

While simulation models such as these are capable of finding acceptable management alternatives, there is no guarantee that other better alternatives for increasing the utility of the forest to its owner do not exist. The problem of determining forest level management strategies which maximise utility for the forest owner under a range of constraints has most often been addressed by the operations research technique of linear programming (LP). Two basic formulations of this problem have been recognised (Johnson and Scheurman, 1977), depending on whether the identity of initial harvesting units is preserved throughout the planning horizon (Model I), or new harvesting units are created from the area regenerated in each period (Model II). Although Model II is less accurate (losing the physical identification of the stand), it can achieve a significant reduction in the number of decision variables required for the equivalent Model I formulation. However, both formulations can have problems in adequately modelling the range of detailed silvicultural options and management regimes that characterise modern plantation forestry management. A substantial body of research on forest level optimisation models has developed in North America, culminating in the adoption of the LP model FORPLAN (which provides for both Model I and II formulations - Johnson *et al.*, 1980) as the primary planning tool of the U.S Forest Service. The work of Nautiyal and Pearse (1967), Ware and Clutter (1971), Navon (1971), and Johnson and Scheurman (1977) was instrumental in this development.

The major forest level optimisation model in New Zealand is FOLPI. FOLPI is fully compatible with the forest simulator IFS, using the same input files and producing identical output reports. The user specifies an objective function and a set of constraints in addition to the volume/value tables in IFS. The problem is then automatically formulated and solved as a Model II linear program, optimising cutting, replanting and crop type transfers for each period. IFS can then be used to explore deviations from this optimum. IFS and FOLPI can together model forest management, harvesting and log transport to mills over a range of time periods.

Before the development of FOLPI, another forest level optimisation model had limited use in New Zealand. CPLAN (Shirley, 1979) was a Model I linear program developed by the New Zealand Forest Service to assist in planning the harvesting and management of state forests. CPLAN is no longer operational, but interest in it is being revived because of the perceived utility of this type of harvest scheduling model for large companies in New Zealand.

Forest estate models have been used in several important forestry studies in New Zealand. IFS and FOLPI have been used in tandem by the New Zealand Forestry Corporation and Treasury Department for forest valuation purposes, and have recently been released for private use (Williams, 1988). IFS was used by the New Zealand Forest Service to derive harvesting and marketing strategies for state softwood supplies to the turn of the century in each of 24 regions (NZFS, 1985a). IFS has also been used to extend the estate modelling approach to the entire national plantation resource. The defunct New Zealand Forestry Council set up a National Exotic Forest Description System (NEFDS - e.g. Collins *et al.*, 1988) which provides detailed information on the entire exotic plantation resource, both state and privately owned. The NEFDS summarises, for each of the country's 107 counties, crop types, net productive stocked exotic forest areas and area/age class distributions by roading class, terrain class, species, ownership and silvicultural type. Growing stock and current annual increment can be derived from these data, providing an indication of forest growth rates. The NEFDS, now maintained by the Ministry of Forestry (MOF), was used in conjunction with IFS to produce the national wood flow projections shown in Table 2-1.

RMS-87 is used by the country's two largest forestry companies (Elders/NZFP Forests, its developers, and Tasman Forestry), as well as by the School of Forestry at Canterbury. Its use in generating wood supply schedules for WPPM is described in Chapter 3.

Log production and bucking models. The output of growth models can also be used as input to models which predict the quality of logs to be produced by a given stand. PROD (Goulding and Shirley, 1979) is such a stand outturn model, providing long-term predictions of the volumes of different log sizes arising from a given stand. PROD generates a diameter distribution for each stand and simulates cross cutting of stems into logs according to a simple set of user defined instructions. PROD is an integral part of the silvicultural stand model SILMOD (Whiteside and Sutton, 1983), now replaced by STANDMOD (Whiteside *et al.*, 1987), used widely in New Zealand for evaluating different silvicultural regimes for radiata pine. LOGRAD is a refinement developed by the Conversion Planning Team at the Forest Research Institute which transforms the log sizes from PROD into predictions of log grade outturn based on expected defects, taper, sweep. *et cetera* (see Whiteside *et al.*, 1987). The full range of models developed by the Conversion Planning Team will be discussed in section 2.2.2.

Models have also been developed for explicitly optimising the cross-cutting or bucking decision process modelled in PROD. Such models ensure that the optimum value is obtained from individual stems, usually by formulating the cross cutting problem as a dynamic program. MARVL (Deadman and Goulding, 1979), a method for assessing recoverable volumes by log types, was the first such system developed for New Zealand and is still used for pre-harvest inventories. AVIS (Assessment of Value by Individual Stems - Threadgill and Twaddle, 1985) is an audit/training system developed at the Forest Research Institute for comparing actual with optimal cutting patterns and determining the resulting loss in value for individual stems. Eng *et al.* (1986) used a combination of linear and dynamic programming to extend optimal bucking strategies to an entire forest of Caribbean pine in Fiji so as to meet market requirements and other constraints. Their algorithm employed Dantzig-Wolfe decomposition, a technique discussed in more detail in Chapter 3.

Single plant industrial models. The vast majority of single plant models involve simulations of the production process in question. This is due to the inability of other techniques (most notably linear programming) to address the random nature of log inputs and machine downtimes, and to model buffer storage space and bottlenecks between processes (Sampson, 1979). Models used in New Zealand include GEMS (Edwards *et al.*, 1987), a general energy and material simulator for the pulp and paper industry; PLYMILL (Ward, 1987), a plywood mill simulation; and a suite of sawmill simulation programs incorporating a linear program for saw pattern selection (van Wyk and Eng, 1987).

GEMS was developed in the USA and imported for use by Tasman Pulp and Paper. The capital intensive pulp and paper and reconstituted board industries have long made use of the latest in automation and process control technology, providing an ideal environment for real-time process simulation. Edwards *et al.* (1987) described such an application, with a distributed control system providing direct input of all major process variables continuously to the GEMS simulator which is then able to adjust automatically chemical concentrations, production rates, *et cetera*. An even more ambitious real time process control application was described by Hara *et al.* (1987) who reported the on-line application of a large scale linear programming model for controlling and supervising the pulping and blending processes in a large Japanese pulp mill. Methods used for reducing computing time in this model are examined in Chapter 3.

PLYMILL and a suite of sawmill simulation models were developed by the Conversion Planning Team. An example of the structure of such simulation models is shown in Figure 2-2, detailing the inputs, outputs and processes of the sawmill simulation models. Alternative models for the first component, sawing simulation, have been developed at the FRI to meet the needs of various users. These include SEESAW, a program for simulating the sawing of pruned logs using interactive computer graphics (Park and Garcia, 1987), and SAWMOD, a more streamlined simulation approach to evaluating sawing patterns and ranking the value of different log types to a particular user (Whiteside and McGregor, 1987). These models are being used in the Sawmill Improvement Program offered by the Forest Research Institute (NZFS, 1987) to illustrate the advantages of modernisation to New Zealand's aging sawmilling industry.

All of these models can help mill managers to identify production bottlenecks, examine the effects of changing wood supplies or processing technologies on production quantities or qualities, and to experiment generally with the dynamic behaviour of production processes. Recent developments in process simulation and optimisation overseas, such as the micro-computer interfacing of linear programming and simulation in GEMSOP (Boyle, 1987), the on-line application of large-scale linear programming in the Japanese mill discussed above, and an increasing use of spreadsheet packages (e.g. Wells *et al.*, 1986; Orr, 1987), will likely be adopted by New Zealand industries in the near future. Although such models are powerful decision aids for operational and tactical planning, their utility for longer term strategic planning is limited due to the necessarily short production periods they simulate.

<u>Integrated industrial models.</u> The vertical integration of several production processes in a multi-product forest industry complex results in many economies of scale and eliminates several transport and processing cost elements from the equivalent single plant production structure. Such integration also results in requirements for enhanced planning, with a company having many possible sources of raw/intermediate materials, and with each process varying in its raw material requirements and producing or consuming different levels of intermediate products. The simplest form of integrated industrial model involves grouping a number of single mill models together and solving each individually. This is equivalent, however, to using stand growth models for forest estate modelling, and will rarely be satisfactory, since optimal strategies for the company as a whole do not necessarily equate to the optimal policies of its component parts operating in isolation.

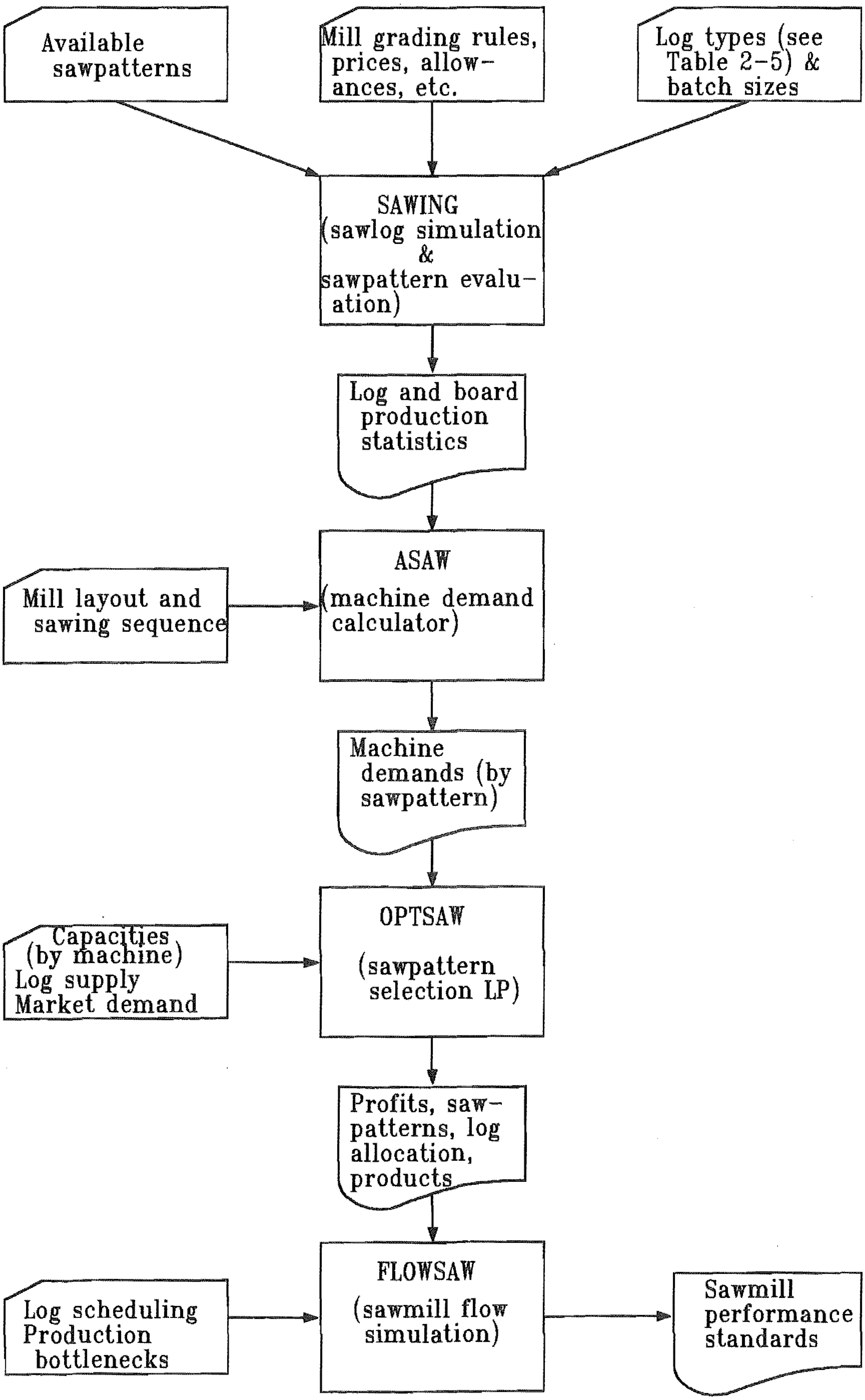

Figure 2-2. The CPPT sawmill simulation suite.

(after van Wyk and Eng, 1987)

The primary class of integrated industrial models in use today are log allocation models. These models are generally LP based and deal with allocating a limited log supply to the various processing options available to the integrated company so as to maximise returns. Figure 2-3 illustrates the general flows of materials and products in an integrated forest company, showing the relevance of log allocation models (and associated bucking or log-making models). Since this class of model is important to the development of WPPM, and since there are few New Zealand examples, a short review of overseas applications follows.

The first such log allocation model (Pearse and Sydneysmith, 1966) used LP to distribute 12 log types and intermediate products optimally among a multi-product utilisation complex in coastal British Columbia. Bailey (1973) produced a dynamic programming algorithm for allocating wood from five forests to a sawmill and pulpmill, also in British Columbia. Dargavel (1978) developed an LP model which, while not allocating logs, determined the optimum mix of silvicultural regimes throughout the industrial plantations of APM Ltd., a large Australian firm, so as to satisfy the wood requirements of the firm's integrated processing complex. International Paper Company in the USA uses a mathematical programming system called LOGS to allocate resources to and production from its two dozen paper mills and 100 other manufacturing facilities (Bender *et al.*, 1981). More recently, Barros and Weintraub (1982) developed a medium- sized LP for allocating the output of up to 300 stands to a sawmill/pulpmill complex in southern Chile. Their model considered a limited number of management alternatives for each stand, as well as the seasonal nature of wood availability and the possibility of log exports. Gunn and Rai (1987) modified their formulation to allow consideration of a greater range of stands and management alternatives. The use of decomposition techniques in this model is discussed further in part 3.5.

For a large integrated firm, log bucking decisions may play a role of equal (or greater) importance to allocation decisions in terms of profitability (see Figure 2-3). Although log bucking and allocation problems have traditionally been solved independently, several recent papers have recognised the desirability of integrating both processes into one model. Bare *et al.* (1979) outlined two approaches: a combined dynamic/linear programming formulation, and a solely dynamic programming formulation. Faaland and Briggs (1984) have developed and applied an application of the latter approach, while Hay and Dahl (1984) have reported an application of the former to a log merchandising/ allocation problem faced by Weyerhauser Company in the southern USA. This approach will be most worthwhile if the company owns significant forest resources or buys wood in full stem lengths and can actually make the bucking decisions itself.

The use of log allocation models in New Zealand was first reported by van Wyk (1983), who developed ROBUST, a single period "process selection" LP model at the Forest Research Institute. Concurrent research

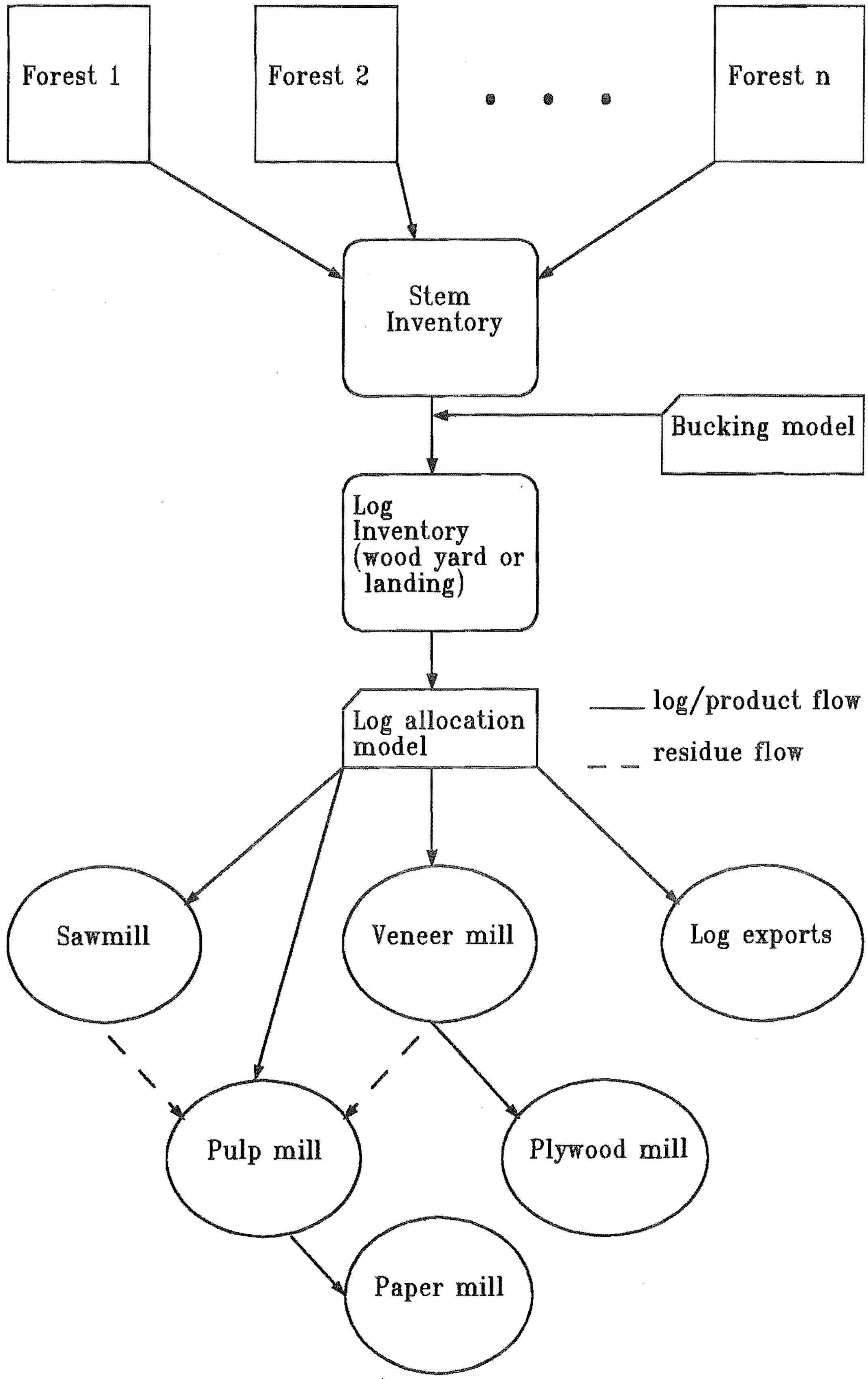

Figure 2-3. Generalised wood flows in an integrated forest company.

was being carried out in the industry, with McGuigan (1984) developing a model called LOGRAM, essentially a modification of ROBUST capable of allowing for multiple manufacturing sites and forest locations. LOGRAM has been used for optimising the allocation of 35 log types from 40 forest regions to the integrated processing facilities of Tasman Forest Industries Ltd. The Conversion Planning Project Team's process selection model (Manley and Threadgill, 1987) is an updated version of LOGRAM which reads log assortment data from other models in the conversion planning suite (see section 2.2.2 for a description of these models). It assumes only one notional market for each product and does not allow explicit representation of imports or exports of final products. Perhaps more importantly for a process selection model, there is no explicit representation of processing costs for different plant variations. Despite its simplicity, the CPPT model can be used to examine some of the broader assumptions associated with process selection.

All of these industrial implementations are limited to modelling single time periods, reducing their effectiveness as long term strategic planning tools. This drawback can be partially alleviated by simulating wood supply scenarios for long term plans (using IFS or RMS-87, for example) and applying the allocation model to the simulation results, period by period. This approach is still recognised as being unsatisfactory, however, as allocation decisions in one period will affect those in all subsequent periods (McGuigan, 1984).

The next part of this chapter defines the concept of strategic planning referred to in the above discussions and describes the level of such planning required most urgently in New Zealand. A review of this most all encompassing form of forestry strategic planning, forest sector modelling, follows, setting the stage for the description of the wood processing planning model that has been devised, in Chapter 3.

2.2 Forest Sector Strategic Planning

2.2.1 Strategic planning: definitions and needs

Over the past two decades, many textbooks and papers have been written on the topics of strategic planning and management. Strategic planning, generally involving long range plans of what business an organisation should be in, is the basis for shorter term operational and tactical planning (according to the terminology of Hartman *et al.*, 1986). The relationship between these different planning levels is depicted in Figure 2-4. In forestry, strategic planning should extend over at least a full rotation (about 30 years in New Zealand), a time span long enough to assess the long term consequences of current decisions. Operational and tactical planning are then constrained by the overall strategic plan to ensure that the organisation is moving towards its strategic goals in its daily operations.

Figure 2-4. A hierarchy of planning levels.

Strategy, the outcome of strategic planning, has many levels, including, for example, marketing strategy, product strategy, and export strategy. The common feature of all levels of strategy and strategic planning is their ability to assist a firm or organisation in adapting to its environment (Webster, 1979). Since all firms or organisations have some type of strategy (whether consciously formulated or not), a confusing array of definitions has proliferated in the literature.

Recently, Hax and Majluf (1988) formulated a unifying definition of strategy/strategic planning by analysing and synthesising definitions from numerous sources. Their definition incorporates concepts of strategy as a means of establishing long term objectives (e.g. Chandler, 1962); as a definition of the competitive domain(s) of the organisation (e.g. Learned *et al.*, 1965); as a unifying and integrative blueprint for the organisation as a whole (e.g. Glueck, 1976); as a response to internal and external forces affecting the organisation (e.g. Argyris, 1985); as a primary means of attaining competitive advantage (e.g. Porter, 1980 and 1985); and finally as a motivating force for *stakeholders* (anyone directly or indirectly affected by the actions of the organisation - e.g. Andrews, 1980). According to Hax and Majluf, strategy:

> is a coherent, unifying, and integrative pattern of decisions;
>
> determines and reveals the organisational purpose in terms of long term objectives, action programs, and resource allocation priorities;
>
> selects the businesses the organisation is in or is to be in;

defines the kind of economic and human organisation the company is or intends to be;

attempts to achieve a long term advantage ... by responding properly to the opportunities and threats in the environment and the strengths and weaknesses of the organisation;

engages all the hierarchial levels of the organisation; and

defines the nature of the contributions the organisation intends to make to its stakeholders.

Methods for strategic planning (i.e. for strategy formulation) range from non-analytic approaches based on the behavioural theory of organisations and the concept of "muddling through" (e.g. Wrapp, 1984) to formal and disciplined processes relying heavily on analytical tools and methodologies (e.g. Ansoff, 1984). Quinn (1980) expressed the need for an integrated approach, combining formal and behavioural analyses. Regardless of the approach taken, successful strategic planning must recognise and balance external environmental opportunities, the organisation's internal strengths and weaknesses, the values of the organisation and its key personnel, and society's (including customers and competitors) expectations of the organisation. Figure 2-5 shows how these factors are balanced in the strategy formulation process.

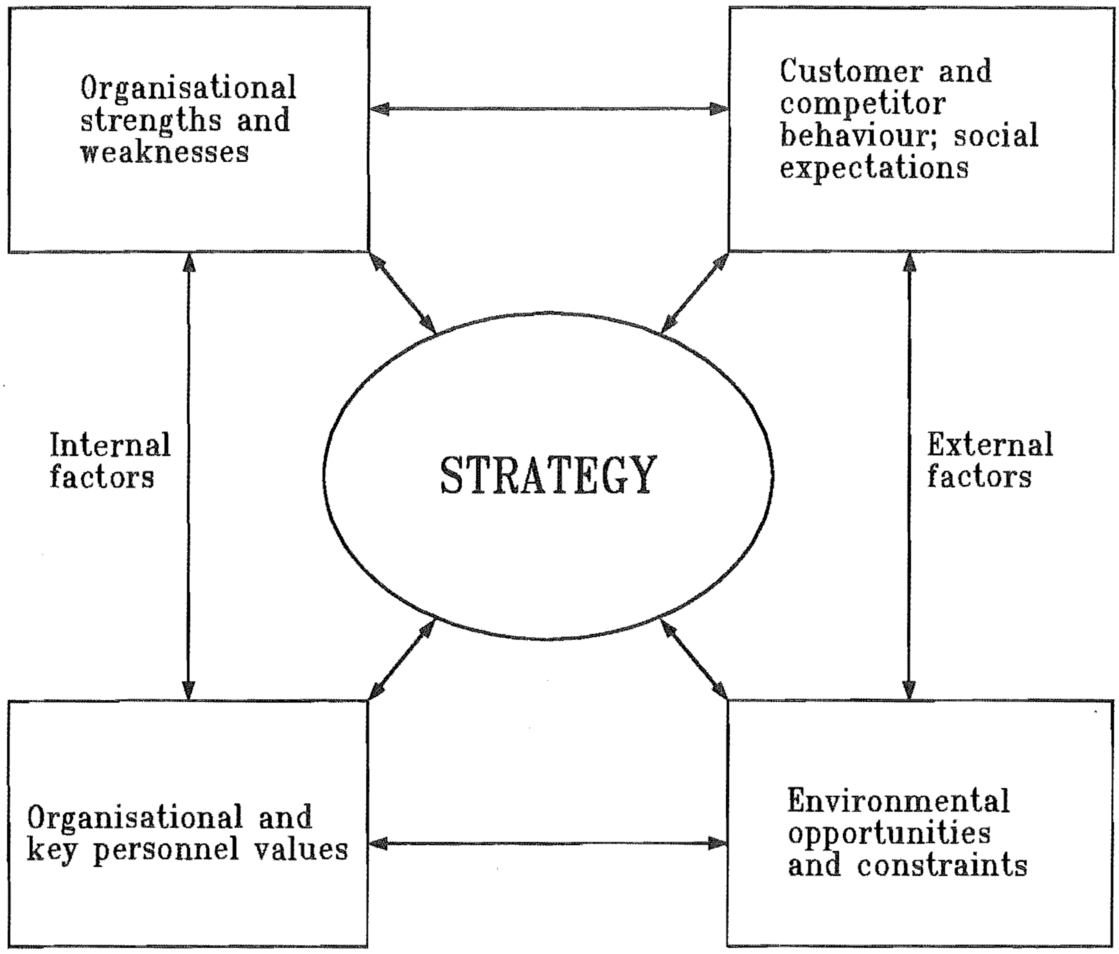

Figure 2-5. The strategy formulation process.
(after Hameresh, 1983)

Forest sectors worldwide have been slow to adopt strategic planning principles. This has resulted from both forest growers and forest processors historically having been production oriented, focussing their energies on increasing productivity, improving recoveries and minimising production costs at the expense of market research and other strategic planning principles. Tedder *et al.* (1987) maintained that a further disincentive for forestry strategic planning was the long time frame involved (many times that required in other industries) due to the long production cycle for wood. This should, however, be regarded as a compelling reason for strategic planning rather than as an obstacle. As Drucker (1983) states:

> But the future always does come, sooner or later. And it is always different. Even the mightiest company will be in trouble if it does not work towards the future. ... By not daring to take the risk of making the new happen, management takes, by default, the greater risk of being surprised by what will happen.

The present New Zealand forest sector has not, in many ways, "taken the risk of making the new happen." It has, at most, paid lip service to the need for strategic planning, despite facing the significant changes in raw materials and markets highlighted in section 2.1.1. Leslie (1986) stated that all-encompassing strategic planning for the New Zealand forest sector was "almost non-existent." Six years earlier, a Development Finance Corporation forest industry study (1980) called for coordinated sector planning, emphasising strategic research into marketing opportunities, processing options, and resource availability and management. While considerable headway has been made in the latter field, relatively little work has been carried out in the former two. This has resulted in the "appalling lack of discipline in the marketing of New Zealand timber overseas" reported by Shirley (1988) and in the sector "(not having) a clue where its markets would be in the 1990's - and the decade (is) only 15 months away" (Hawkins, 1988a). This uncertainty regarding markets has been compounded by the recent restructuring of environmental administration and the decision to privatise the 600 000 ha State forest resource currently managed by the Forestry Corporation (Thomson, 1989).

These factors have resulted in calls for a national forest industries council (Ballard, 1988) to provide a unified body for planning the development of the sector. While this has not been the first time that such a body has been proposed (the New Zealand Forestry Council held responsibility for sector planning from 1983 to its disestablishment in 1986), the current proposal for a 30 member council has generated a level of support throughout all segments of the sector not previously seen in New Zealand. This support, a product of the current climate of uncertainty in the sector and a growing realisation that New Zealand's small size in relation to its international competitors requires a common front, will ensure that any council created has the financial and technical backing of the entire sector. As one of the prime roles of a national forest industries council will be to "provide input and sponsor strategic planning in ... sector development" (Ballard, 1988), it is likely that planning models for facilitating this role will be urgently required. Perhaps more important, however, is the likelihood that the development and implementation of such models will be fully supported by the sector for the first time. No longer will New Zealand forest sector planning be "almost non-existent." The following section surveys the range of forest sector models currently available for such planning, worldwide and in New Zealand.

2.2.2. Forest sector planning and modelling

Forest sector planning has been defined as "a kind of strategic mapping of the future, which will assist the sector to navigate" (Hunter, 1986). Such planning is distinguished by its scope (encompassing growing, processing and marketing of forest products for an entire sector) and by its indicative (versus prescriptive) nature. While some integrated mill models and forest estate models have been used in strategic planning contexts for individual companies or components of the sector (e.g. Weintraub *et al.*, 1986; Weintraub and Navon, 1976; NZFS, 1985a; Hay and Dahl, 1984; Bender *et al.*, 1981), none has the capability to model the complex interactions present throughout the sector. Using such models independently to derive sectoral plans parallels using stand growth/single plant models for forest estate/integrated plant modelling, with the same risk of unsatisfactory results. Forest sector models are those developed specifically to incorporate the multitude of variables involved in examining an entire forest sector, and to indicate strategic alternatives for that sector.

Forest sector models can be categorised by their scope (global and international, national and regional), as suggested in Figure 2-1, as well as by the methodology they employ to generate alternative strategies. Dynamic simulation, mathematical programming and econometric spatial equilibrium models (which aim to determine equilibrium forest product prices in each of a number of trading regions) are most prominent in forest sector modelling. The spatial equilibrium approach is particularly relevant in models emphasising forest products trade, and is based on the work of Samuelson (1952). While these three techniques dominate, others such as optimal control theory (Dyer and McReynolds, 1970) and systems dynamics (Forrester, 1961) have seen limited application. All of these modelling techniques are often viewed as complementary, with spatial equilibrium models usually incorporating aspects of simulation or mathematical programming and vice-versa.

Nilsson (1983) has suggested several requirements of models designed to analyse forest sectors. He proposed that such models should:

(i) be usable for several time periods;

(ii) be regionalised;

(iii) allow alternative forest management options;

(iv) deal with each industry as a separate unit;

(v) allow analysis of several goals simultaneously;

(vi) allow alternative usage(s) of forest biomass; and

(vii) consider the financial aspects of the sector.

The following review examines models with a global or international emphasis first, then national/regional models (grouped by continents). It attempts to classify each model according to its methodology, and to evaluate each (where possible) according to Nilsson's criteria.

Global and international models. The IIASA (International Institute of Applied Systems Analysis) forest sector project ran from 1981 to 1985, supported by more than 100 collaborators in 35 countries. The project resulted in the world's first comprehensive computer model of the global forest sector. This model, known as GTM (Global Trade Model - Dykstra and Kallio, 1986), is classified as a partial market equilibrium economic model employing non-linear programming. It therefore has aspects of both the spatial equilibrium and mathematical programming classifications discussed above.

IIASA's primary goal in developing GTM was to study the long term development of production, consumption and trade in forest products at a global level. The model finds the market equilibrium for 16 forest products in 18 world regions for each of 10 five year time periods, without considering the influence of any future time period. Model results for each period are updated automatically to reflect conditions in the following period and the model is then re-run, resulting in 10 periodic solutions (this technique, known as recursive programming, is discussed in Chapter 3). The comprehensive data base and the model itself have been made available to member countries to facilitate a common approach to sectoral planning. The data base varies in quality for different countries, but generally includes at least patterns of consumption and supply for various forest products in participating countries. Both the data base and model parameters can be modified by users to reflect their own sectoral concerns. One such use has involved an examination of the effects of atmospheric pollution and related forest dieback in Europe (Dykstra, 1986); other non-global applications of GTM are summarised in the following sections.

GTM is an economic (and thus financial) multi-period, multi-region model that considers each forest industry separately. However, due to its broad global emphasis, GTM does not cater for alternative forest management options. It incorporates four classes of growing stock (large and small, coniferous and non-coniferous) which are upgraded by simple growth functions between periods. Fuelwood is the only non-timber use of forest biomass allowed. The non-linear objective function is designed to achieve a balance between demand and supply for all products and as such GTM does not lend itself to goal/multiple objective formulations.

Nonetheless, the model has proven useful in analysing a number of global issues facing the forest sector, with scenarios of economic growth, trade liberalisation, acid rain, increasing timber exploitation in the USSR, a stronger/ weaker US dollar, and climatic warming modelled to date. IIASA is now offering training in the use of the model to interested countries, and has joined forces with IUFRO to ensure that a strong network for exchanging the results of regional implementations is established.

The mathematical structure of GTM was based partially on a spatial equilibrium model of international trade in pulp, paper and newsprint developed by Buongiorno at the University of Wisconsin (Buongiorno, 1986; Buongiorno and Gilless, 1984) This model was developed specifically for the North American pulp and paper industry (see the description of PAPYRUS below) and has had little use at an international level.

Likewise WAMM (World Assessment Market Model - Brooks, 1987), the US Forest Service world trade model developed for the 1990 Renewable Resources Planning Assessment (RRPA), focusses on the international forest products trade and markets only insofar as they affect US producers. This spatial equilibrium model is still being tested at the international level. A formulation incorporating 12 products and aggregating timber/product supply/demand into sets of 12 broad regions has been reported by Brooks (1987). The model is solved using a simulation approach known as reactive programming (Tramel, 1965) which iterates to find a "sufficiently approximate" solution to the spatial equilibrium problem. This model is essentially a trade model, with no provision for forest management or alternative goals/uses of biomass. WAMM is an extension of the North American Timber Assessment Market Model (TAMM), described below.

Resource Information Systems, Inc. (RISI) is an economic forecasting company in the USA specialising in the forest products industry. Young (1986) described the development and use of the RISI international pulp and paper model, an econometric model incorporating a database of some 15 000 time series. These time series range from 1970 to the present and include data on general economic conditions, production, imports, exports, capacity, apparent consumption and furnish mixes for six grades of pulp and five of paper/board. The model itself consists of approximately 3 000 equations and is separated into four components (world paper and paperboard, world total and market pulp, Norscan and Brazilian market pulp and world pulp production costs). Its primary use is in forecasting the outlook for the world pulp and paper industry on a 5 to 15 year horizon. These projections are published quarterly and provide a valuable data base for global modelling. The accessibility of the RISI model and data base has been greatly enhanced this year, with its transfer to personal computers nearly complete.

Nilsson (1981 and 1983) has provided a general description of strategy choice for the international forest sector using a mathematical (linear) programming model developed and maintained by the World Bank (Bergendorff and Glenshaw, 1980). His description focused on the Swedish forest sector, but was applicable on a global scale. Nilsson proposed the requirements for forest sector models listed above after considerable work in developing and applying the World Bank Model.

Sedjo (1986) developed a dynamic simulation model to examine the economic feasibility of plantations in the southern hemisphere as compared to northern, and the effects of such plantations on the economics of temperate climate forestry. While only two final products are considered in the model (wood pulp and sawn timber), the analyses carried out indicate that the economics of plantation investments in many Southern Hemisphere regions that have not been traditional forest product producers are quite favorable. The model does not fulfill many of the sectoral requirements listed above, and will therefore prove most useful if used in tandem with a true forest sector model (either global or national) to examine alternative wood supply strategies. Sedjo and Lyons (1987) extended this work to develop an optimal control theory approach to modelling global supply and demand for industrial roundwood.

A simulation model of tropical hardwood supply and world trade has been developed by Grainger (1987). This model, known as TROPFORM, predicts forest reserves in each of 21 producing regions to 2020, then forecasts the price of these supplies. Consumption is then projected for five importing regions (Japan, Europe, USA, Other Asia and rest of world) and three broad producing regions (Africa, Asia and Latin America). The consumption function is based on that used in GTM, with processed wood consumption (plywood, sawnwood) converted to roundwood equivalents. The final component of the model is a linear program which allocates supplies from producing to importing regions so as to minimise transportation costs. The model has been used to show the effects of changing import/export trends, deforestation, shorter harvest cycles and plantations on tropical timber supply and consumption. Despite the model's narrow focus (dealing only with one commodity) and the lack of any capacity to examine alternative objective/forest management/biomass options, it has helped to point out the need for massive investment in natural forest management in the tropics if timber supplies are to be maintained.

Before turning to national and regional models, the contribution of the Food and Agriculture Organisation of the United Nations (FAO) to global forest sector modelling should be noted. The FAO has a Division of Forest Industry Studies which has carried out world wide studies of wood and wood processing industries (e.g. FAO, 1983) and which also compiles quarterly forest products statistics worldwide (e.g. FAO, 1986). The FAO uses this extensive data base in their own econometric models to provide yearly projections of worldwide production and consumption of forest products to 2000. The ready availability of such data is essential to both global and national forest sector modelling and has contributed substantially to the development of models such as GTM.

North America. Perhaps the best known forest sector model currently in use is TAMM (Adams and Haynes, 1980), the Timber Assessment Market Model used by the US Forest Service to assist in the analysis of long term trends in resource use and status. The structure of TAMM was used as a loose guideline in the development of GTM (which employs a completely different solution mechanism however), and served as the basis for the development of WAMM, the world market model described above. Its structure was also employed in a model of trade in tropical logs and sawnwood between Africa and Europe (Adams, 1985). TAMM is a spatial equilibrium model of the US forest sector which employs reactive programming to simulate equilibrium trade flows, prices, *et cetera*. The current version of TAMM (Adams and Haynes, 1986) incorporates five final product groupings, nine timber/final product supply regions and six final product supply regions. It is being revised for the 1990 RRPA to include more realistic demand relationships for solid wood products, to incorporate (and simultaneously solve) a new model of hardwood lumber and stumpage markets (Binkley and Cardellichio, 1983), to utilise results from the Buongiorno/Gilless model (see below) of the pulp and paper sector, to interface with a more comprehensive timber inventory projection model (TRIM - Tedder, 1983), and to accept import/export projection inputs from WAMM. Figure 2-6 illustrates the proposed structure of TAMM following completion of these revisions. TAMM meets all of Nilsson's criteria with the exception of multiple goal analysis.

The "fibre products" (pulp, paper and board) sector in TAMM is modelled using a system developed by Gilless and Buongiorno (1987). This system, known as PAPYRUS, evolved from the international model briefly mentioned above. PAPYRUS is a spatial equilibrium model of the North American pulp and paper industry which employs linear programming to determine optimal equilibrium prices, production, consumption, imports, exports and fibre inputs to 2000. The model recognises 14 commodities, 11 supply and 12 demand regions (all but three North American). PAPYRUS employs recursive programming, a technique discussed in greater detail in part 3.5, to update the model between periods, so removing the time dimension from the linear program. PAPYRUS will also be used in the 1990 RRPA, and has been used to examine the effects of per capita income, manufacturing costs and capacity growth on the North American industry. Its focus on one aspect of the sector precludes direct analysis of alternative forest management/biomass uses, and the spatial equilibrium framework restricts the objective to maximising net producer and consumer surplus (essentially net revenue). Nonetheless, PAPYRUS contains the most detailed formulation of wood processing (albeit only one aspect thereof) in this review.

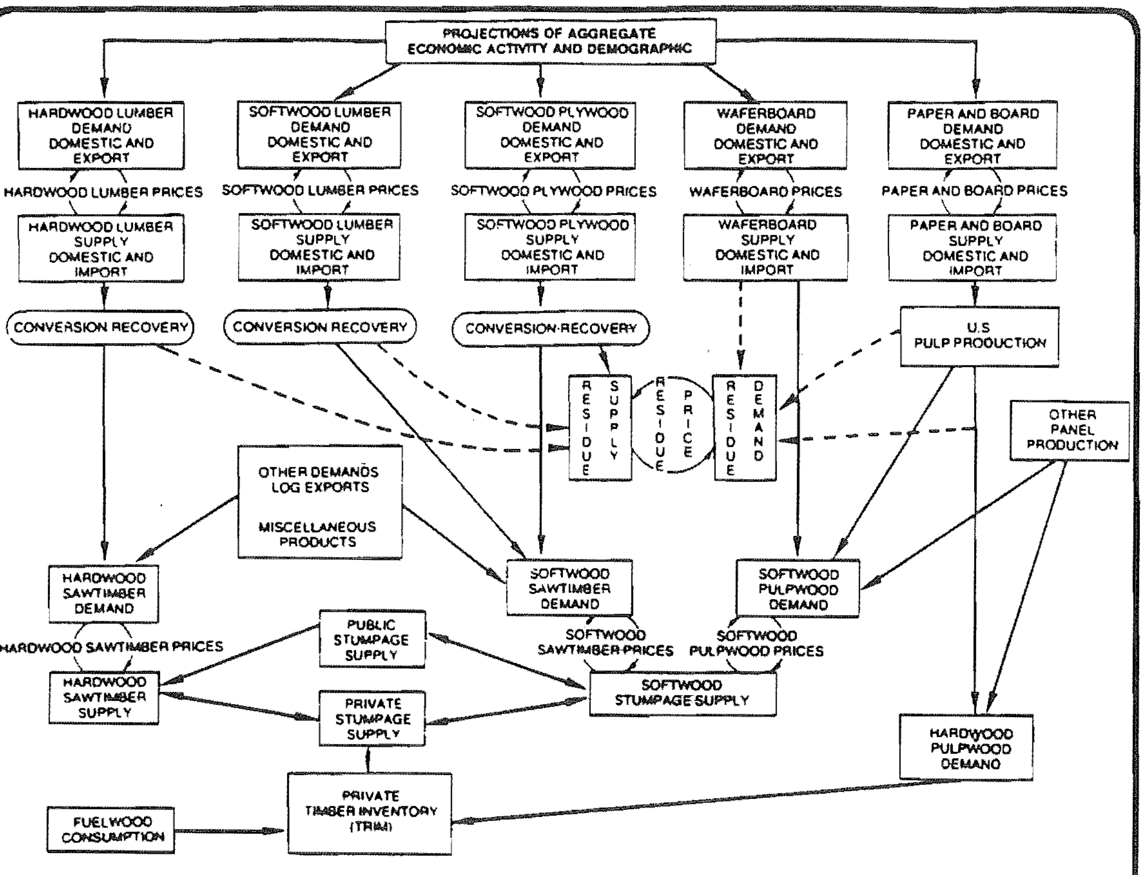

Figure 2-6. Proposed structure of TAMM.

(Source: Adams and Haynes, 1986)

Ince *et al.* (1987) used PAPYRUS and TAMM to examine the effects of technological change in US wood processing industries on the supply, demand and anticipated uses of timber resources. This study involved forecasting current and future technological changes possible in the wood processing industry over the next 50 years, along with the associated changes in wood inputs and manufacturing costs. These data, derived from extensive literature review and expert consultation, were then used to drive PAPYRUS and TAMM, resulting in an economic model of technological change in wood products processing. Such an application illustrates the potential of sectoral planning for anticipating likely developments in the industry.

In Canada, the Forest Economic Policy Analysis (FEPA) project of the Canadian Forest Service and the University of British Columbia resulted in the construction of a Canadian forest sector model. This model used Canadian forest inventory data and an economic timber supply model in conjunction with modified versions of TAMM and PAPYRUS to generate equilibrium prices, production, consumption and trade flows for sawntimber, plywood and pulp in British Columbia to 2000 (Pearse *et al.*, 1984). The output of these models was integrated into a large scale linear program, based on the Swedish forest sector model developed by Nilsson (1983). This approach allowed the specification of up to three different objective functions: maximisation of profit to the sector; maximisation of the sectoral contribution to balance of payments; and maximisation of the sectoral contribution to gross national product (Nilsson, 1984). While the resulting model meets all of Nilsson's criteria, application to other regions of Canada (and to Canada as a whole) did not eventuate, primarily due to excessive computer memory requirements.

Percy (1986) developed a general equilibrium model of the British Columbia economy with five of nine sectors related to forestry. This relatively small econometric model (less than 60 equations) was used to simulate the effects of several shocks to the province's forest industry on the provincial economy. These shocks included increases in log exports and ocean freight rates, decreases in world softwood lumber prices and provincial allowable cuts, and the imposition of duties on forest product exports to the US. The model has since been used to simulate the effect of the softwood export tax on the entire Canadian economy (Percy and Constantino, 1987) and to examine forest policy issues in Indonesia (Percy, 1987). This model is necessarily broad, predicting economic aggregates and changes in sectoral output for a small number of regions (two in British Columbia). Its utility lies in analysing forest policies and modelling intersectoral linkages and is enhanced by its availability on a personal computer spreadsheet package. Although the model contains no representation of forest management or alternative biomass uses and provides only broad indications of sectoral change, its ready availability and rapid solution times (as low as one minute) make it ideal for preliminary sectoral analyses.

<u>South America.</u> Forest sector modelling applications in this region are sparse and poorly documented. Brepohl (1979) reported a simulation model developed to analyse the flows of products in the Brazilian forest sector, but few details of the model were given. Gane (1986) has applied a systems dynamics simulation model called TIMPLAN to the Argentinean forest sector. Four final products and nine crop types were modelled, resulting in projections of harvesting, planting, production, imports, exports, employment and foreign exchange earnings for up to 100 years ahead. While this model appears to meet most of Nilsson's criteria for a forest sector model, there is no guarantee that the strategies generated by it are optimal. In addition, its use in the Argentinean sector was severely limited by data availability, brought about by a 600 per cent inflation rate (making cost and price data difficult to coordinate) and lack of any regularly reported statistics for the forest sector. It was nonetheless used to examine alternative scenarios of domestic and export demand, reduced planting rates, and a switch from pulp to particleboard production.

Most other South American countries suffer from the same lack of data and high inflation rates as Argentina, making the construction of meaningful forest sector models difficult. Unfortunately the need for such modelling in these countries is great, with forests capable of generating valuable foreign exchange and jobs in the often fragile economies. Chile is making good progress in collecting forest industry statistics, and a model for that country's rapidly expanding forest sector may soon be developed.

Scandinavia. Scandinavian countries have a long history of forestry and were among the first to build and use forest sector models for policy analysis. The first such model (SOS) used systems dynamics to model the entire Scandinavian sector (Randers, 1976). Lönnstedt and Randers (1979) adapted this model for a study of the Norwegian sector, while Kuuluvainen and Seppälä (1983) developed an adaptation called MESSU for the Finnish forest sector. All of these simulation models covered the entire forest sector (growth to product markets), but production was highly aggregated (e.g. only one "product" was modelled in MESSU). As with all simulation models, these approaches could not ensure that policy options modelled were optimal.

Since the development of the first Scandinavian forest sector model, the individual countries in the region have followed their own paths in model development. The Finns developed a dynamic linear programming formulation of their sector, based on their work with MESSU (Kallio *et al.*, 1985). This model incorporated seven industrial products, a forest subsector with 21 age classes, and allowed analysis of various linear or non-linear objectives. It meets all of Nilsson's criteria (with the possible exception of alternative biomass uses) and was an impetus to the development of GTM, in which the Finns played a significant role.

The Finnish sector has made extensive use of GTM in analysing their own sector, examining the effects of acid rain and tariffs, and of changes in stumpage prices and exchange rates (Seppälä and Seppälä, 1987). However GTM's extensive use of computer resources, its aggregated products and regions, and its out-dated data base (the base year is 1980) prompted the Finns to adapt GTM extensively to their own requirements. The resulting model, known as MESTA, has been implemented on a personal computer using a specialised LP code, achieving substantial gains in solution times (8 versus 20 minutes) over GTM which uses a standard mainframe LP code. MESTA uses the three main Finnish forest groups (pine, spruce and non-coniferous - primarily birch) and models 24 forest products (versus 16 in GTM). Only two regions are considered - Finland and the rest of the world. Plans to introduce further regions and bilateral trade hinge on the solution of data problems in the resulting large scale model (Seppälä and Seppälä, 1987). MESTA has recently been used to evaluate the capacity of the Finnish forest sector to expand to utilise the increases in timber production targeted in the country's Forest 2000 programme (Anon., 1986).

Finland's worldwide forest consulting firm, Jaakko Poyry, have developed a model for examining the long term planning problems in forest industries (Kirjasniemi, 1986). This mixed integer mathematical programming model focusses on important structural factors in the industry, including competition, market changes, the economic environment and technical development, and aims to assist in determining optimal industrial structure. The model has been used to assess optimal levels of integration for forest products firms in Scandinavia. Curiously, for a model that professes to assist in the "long term planning problems of the industry", it can model only single time periods. It also has no real spatial dimension, proposing instead to analyse mill location problems via case studies. Finally, no provision is made for the analysis of multiple objectives in this model.

Swedish forest sector modelling parallelled that of Finland in its early stages, but has recently diverged, utilising simulation approaches as opposed to the mathematical programming emphasis of the Finns. Lönnstedt (1986) has described one such dynamic simulation model of the Swedish forest sector. This model comprises two competing forest sectors, one representing Sweden and the other all competing forest sectors. Both components model the development of demand, product markets, industry, and forest management. Lönnstedt's model served as a basis for the most recent Swedish effort, the forest sector model reported by Lönner (1987) and Lönner *et al.* (1986). This approach focusses on the interactions between forest, industry and market subsystems, rather than on the specific details within these sectoral components. It also incorporates Lönnstedt's consideration of the Swedish sector in relation to all other competing forest sectors (usually 3 to 5 main competitors are modelled). The model operates with up to four 5 year periods, five product groups, and a detailed breakdown of Swedish forests into region, ownership, yield, age, management, species and volume classes. Different scenarios are modelled by varying parameters in three main groups: forest policy, general economic development and/or market development. The cost competitiveness of the competing sectors is then determined by the model and increases in market share allocated accordingly. The model has been used to analyse investment decisions in this manner, basing the decision to invest in new (or close down existing) capacity on expected market share. The Swedish forest sector model satisfies Nilsson's criteria for such models, but has the disadvantage (like all simulation models) of being unable to identify *optimal* strategies. An added disadvantage is the model's dependence on reliable cost data from competing countries, a requirement which is often difficult enough to satisfy at home.

Not all forest sector modelling in Sweden is based on simulation. Johansson (1986) described a structural change model for the Swedish industry. This model first employs a technique known as vintage analysis (Salter, 1960) to model the process of productive capacity obsolescence and renewal. Optimum investment and production levels for each region in the model are then determined via mathematical programming, subject to regional production and employment constraints. The model has only been applied to a single region, with two broad categories of forest products (paper products and wood products) considered and a less than complete representation of the financial aspects of the forest sector. It does not consider forest management or alternative biomass use; nor does it allow for multiple goal formulations.

Nilsson, one of the pioneers of forest sector modelling in Sweden and the world, has been involved in the development of many of the Swedish sector models (see the above section on global models). He recently reviewed the performance of GTM as applied to Sweden (Nilsson, 1987) and concluded that major reconstruction of the model and its database, along with changes in the attitudes of the Swedish industry to the model, were necessary before it could be successfully implemented there. He proposed a programme of reconstruction and alternative model development (e.g. Lönner, 1987) to meet Sweden's needs.

In Norway, the forest sector is very much smaller than in Sweden and Finland, earning only 3 per cent of export earnings and 2 per cent of GDP in 1981 (Solberg, 1986). Forest sector modelling has become increasingly based on large scale econometric models developed for the country as a whole since the SOS studies of the late 1970's. Solberg (1986) described the application of a macro-economic multi-sectoral growth (MSG) model of the entire Norwegian economy to forest sector planning. This model, comprising 38 sectors (only three related to forestry) and 20 regions, is described as an inter-regional input-output model utilising Cobb-Douglas production functions for each producing sector (see Richardson, 1972, for a description of such models). It determines equilibrium prices for all products in all regions over a 20 - 30 year horizon. MSG was used by Baudin and Solberg (1987) to forecast the demand for sawnwood in Norway, based on a logarithmic regression model of substitution between sawnwood and other products (particleboard, fibreboard and gypsumboard). Such forecasting methods are necessarily broad, given the scope of the model used. MSG meets few of Nilsson's criteria for forest sector models, apart from its regional and multi-period structure. However, in economies like Norway's where forestry is a relatively minor component modelling such as this can provide adequate guidelines and projections for policy makers.

Europe. As described above, the effects of acid rain on European forests have been modelled by Dykstra (1986) using GTM. A second European application of GTM is in Austria, where Kornai and Schwarzbauer (1987) have adapted the model to Austrian conditions. The resulting model, called ATM, is made up of 9 regions and 14 products of particular relevance to Austria. The model structure is identical to GTM, but there are plans to derive new demand functions compatible with the ATM product groups.

The Austrians have also applied the simulation model developed by Lönnstedt (1986) to an analysis of their sawmilling industry (Lönnstedt and Schwarzbauer, 1984), and are working on a similar model for their entire sector (Kornai and Schwarzbauer, 1987). They hope to be able to test the relative advantages/disadvantages of simulation and optimisation models by comparing the results from this model to those from ATM.

France has also developed a forest sector model based on Lönnstedt's simulation model (Lönnstedt and Peyron, 1987). The French adaptation, known as FIBRE, models only the Burgundy regional forest sector, while competing forest sectors have not been included. The resulting model is small enough to run on a personal computer and has been used to analyse the development of the Burgundy forest sector to the turn of the century. Plans to expand FIBRE to include other French forest regions hinge on overcoming difficulties in data availability and consistency, common problems in forest sector modelling. Such an expansion of FIBRE could also tax the memory of a personal computer and may require that the model be transferred to a larger system.

References to other European forest sector models are relatively sparse. Signorotto (1982) developed an econometric model of the Italian forest products sector, including some secondary manufacturing options. Ulrich (1984) used a simulation approach to model materials flows in the Swiss forest sector, emphasising the production and consumption of softwood timber. Both of these models are limited in the range of products they include and in their ability to model alternative forest management/objectives and/or biomass uses.

USSR/Eastern bloc. Examples of forest sector planning models in this region are difficult to find. GTM's treatment of centrally planned economies (primarily the USSR) has been criticised as being a weak link in the model structure (Cardellichio and Adams, 1987). The model needs to be restructured to allow more flexibility in allocating increased Soviet harvest levels.

The Soviets themselves contributed to the development of GTM and have carried out numerous supply and demand projections for forest products, although few of these have appeared in the West or in English. Geizler and Knyazeva (1982) developed an econometric optimisation model to determine the balance of wood consumption for integrated utilisation plants in the northern USSR. Familiarity with the results of such models could help guide the restructuring of the Soviet sector in GTM.

Hungary contributed to the early development of GTM also, and developed a simulation model of their forest sector in the process (Ban *et al.*, 1982). This model was loosely based on the early Scandinavian approaches described above.

Pacific rim. The Pacific rim (or Pacific basin as it is sometimes called) is a region of increasing importance in world forestry, containing the world's largest forest products importing country (Japan), large-scale exporters of tropical hardwoods (Malaysia, Indonesia, Philippines *et cetera*), and the potential for considerable growth in both demand and supply of forest products. New Zealand is part of the Pacific rim, but models dealing specifically with this country's forest sector are reviewed separately in the following section. This will allow a clearer picture of the state of forest sector modelling in New Zealand to emerge.

Bangladesh is not normally considered a Pacific rim country, but because of its proximity to South East Asia, it is considered in this section. Edelman *et al.* (1985) developed a forest sector simulation model for Bangladesh as part of the FAO Forestry Sector Planning Project. The model projects the demand for a wide range of forest products (from matches to newsprint) to 2010 using equations based on population (stratified by wealth and location), literacy, and per capita consumption of various forest products. Supply projections for three log types over the same period are based on estimates of standing volume, growth rates, losses due to encroachment and the percentage of standing volume in each log type for both natural and plantation forests. The model then balances these supply and demand projections for each period and each of four regions, identifying surpluses or deficits for each forest product in each region and for the country as a whole. While this model does not examine each industry as a separate unit or consider the financial aspects of the sector, it has proved to be a most useful indicative planning tool. It has been used to examine the effects of decreases in per capita fuelwood demand (due to forecasted substitution of kerosene and natural gas), gradual increases in logging in national forests, and increased growth rates in community forests (due to forecasted effects of social/community forestry programmes). The model is readily accessible to forest planners, having been implemented on microcomputer.

The FAO sectoral planning project has produced industry/sector studies in other Pacific rim countries. The application of Percy's (1987) econometric model to the Indonesian sector is the most recent example. Earlier studies in Malaysia and the Philippines (e.g. FAO, 1979) resulted in enhanced sectoral and industrial planning in these countries.

Hyman (1986) developed a linear programming model (FUELPRO) to analyse policy options for dealing with wood fuel shortages in the Philippines. The model helps decision makers to select an optimal mix of policies (from a group of nine ranging from reforestation to kerosene substitution) to maximise social welfare (based on subjective weightings of objectives) subject to energy and environmental constraints. Although this single product, single period model cannot be used for planning at a sectoral level, its treatment of one of the most important forest products in developing countries worldwide warrants its inclusion here.

McKillop (1973) developed an early spatial equilibrium model for analysing trade in softwood logs and sawntimber from the USA and Canada to Japan. His model attempted to recognise the impact of alternative supply sources for the Japanese market (the Philippines), and other demand regions for North American wood (the UK). Despite its limited scope in terms of products, forest management options, objectives and alternative uses of forest biomass, this model laid the groundwork for later more sophisticated trade models such as TAMM and WAMM. Indeed, the first planning exercise to be carried out with WAMM (the US Forest Service world trade spatial equilibrium model discussed above) was an analysis of trade in coniferous logs and sawn timber in the Pacific basin. Brooks (1985) described a number of problems (collection of price and cost data, a lack of appropriate resource data for all regions and difficulties with the spatial equilibrium approach) which had to be overcome before the analysis could begin.

The Japanese use a combination of simulation and econometrics to model their forest sector. Nomura and Yukutake (1982) reported the results of 30 year simulations with such a model, identifying some of the problems associated with large numbers of small scale private forest holdings on sectoral planning. This model differentiates products by their origin, including sub-models of foreign supply, and thus recognises perceived quality differences within a given product.

Kishine (1986) reported another combined econometric/ simulation modelling approach to policy formulation and evaluation in Japan. This model consists of two parts: an allocation model for forest land which determines economic harvest levels and an economic/welfare/ environment model which simulates the effects of different policy decisions on each of these three factors. This model could prove useful if it were used in tandem with the simulation model described above, which provides a more detailed breakdown of products in the Japanese sector.

Vincent (1987) described an econometric spatial equilibrium model (JIMP) for examining trade in hardwood logs, lumber and plywood between Japan and South Seas nations (Malaysia, Philippines and Indonesia). JIMP was based on the work of Adams in TAMM and the Africa-Europe trade model discussed above. It includes only the four supply and demand regions and three products listed , and has been used to model a single period only. JIMP was used to examine the effects of log export restrictions, exchange rate fluctuations and changes in tariffs on trade flows between and welfare within the four model regions for 1980.

Katz (1987) developed another spatial equilibrium model, also based on TAMM, of log and sawn timber markets in the Pacific rim region. PRIMM, as this model is known, consists of six supply regions (including New Zealand but not Chile or Australia) and five demand regions (including New Zealand, Chile and Australia). This model's main difference from TAMM is that it recognises the non-homogeneity of timber products based on species differences. That is, it allows for continued trade of seemingly uneconomic products on the basis of consumer preference. The model has so far been used only to attempt to reconstruct production, consumption and trade flows for Douglas-fir and radiata pine lumber for a single period (1983).

Australia became involved in the development of GTM at an early stage (Batten, 1983) and proposed an ambitious system of models for its own sector to complement GTM. This system was to incorporate a forest sector analysis model for Australia, a structural change model (see Johansson, 1986, above), GTM, and existing national and multi-regional multi-sectoral econometric models already in existence in Australia. Although this system was never actually implemented, the Australians have adapted GTM and have carried out preliminary studies of Pacific rim forest products trade (Bigsby and Kornai, 1987). The resulting model, known as OTM, has 13 regions (including one each for Australia and New Zealand instead of GTM's single Oceania region). Other changes made to the model arose largely from the separation of the Oceania region (e.g. more accurate values for the distance between Australia and New Zealand had to be input) and the aggregation of other regions. Problems arising from this restructuring included bi-directional trade loops appearing in model solutions (regions exporting and importing significant quantities of the same commodity due to the aggregate nature of model commodities) and assumptions of hardwood substitution in GTM proving to be invalid in this region. Unfortunately, no results of OTM have yet been published.

New Zealand. Table 2-4 presents an overview of the modelling efforts which have been taking place in New Zealand over the past ten years, showing the developer(s) and main purpose for each of thirteen models along with inter-model linkages. Some of these models (e.g. IFS, FOLPI, RMS-87, LOGRAM) have been used to model components of the sector, rather than the sector as a whole, and have already been discussed. Although some of the models in Table 2-4 now have limited use or are obsolete, each has contributed to the advancement of forest sector modelling in New Zealand.

Forest sector modelling research was carried out by the now disestablished New Zealand Forest Service and Forestry Council and is currently proceeding at the Forest Research Institute (FRI) in Rotorua, at the Ministry of Forestry in Wellington, at the University of Canterbury and, to some degree, in industry and other agencies. The role of the ex-Forest Service in forest sector planning evolved from one of active model development to one of data collection, standardisation and reporting for the benefit of all planners. This latter role has now been assumed by the Ministry of Forestry's Policy Division, who compile and report all forestry statistics.

The Forest Service had statutory responsibility for forest sector planning until 1983, at which time it was transferred to the New Zealand Forestry Council (a grouping of industry and government forestry planners). From 1981 to 1983 the Forest Service developed and implemented a linked set of simulation models to meet their planning responsibilities. This set of models, used to determine resource flows and economic indices associated with given forest development/ utilisation scenarios, consisted of:

Table 2-4. Forest sector planning models in New Zealand.

Model	Developer(s)[1]	Main purpose	Linkages
IFS	NZFS, 1981 (Garcia-FRI)	forest estate planning; growth and volume forecasts	RSUM, MOVPRO, GROHA, FOLPI, HMS, NEFDS
GROHA	NZFS, 1981 (Levack-HO)	simulates requirements for growing, harvesting	IFS, RSUM
MOVPRO	NZFS, 1982 (Lee-HO)	simulates transport, processing and marketing	IFS, RSUM
RSUM	NZFS, 1981 (Lee-HO)	regional resource flow summaries and indices	IFS, GROHA, MOVPRO
FOLPI	NZFS, 1984 (Garcia-FRI)	optimal harvest strategy	IFS
WOOD2	NZFS, 1984 (Cavana-HO)	national policy analysis	-----
HMS	NZFS, 1985	wood availability schedules (State only)	IFS
NEFDS	NZFC, 1985 MOF, 1988	current resource data (State and private)	IFS, RMS-87
SILMOD	NZFS, 1982 (FRI)	economic stand out-turn predictions (now replaced by STANDMOD)	-----
CPPT	NZFS, 1985 MOF, 1987 (FRI)	link silviculture and processing to market requirements	SILMOD/STAND-MOD, IFS, FOLPI
FORSE-MODEL	U of C, 1983 NZFC, 1986	national/regional forest sector planning	-----
LOGRAM	Tasman, 1984 (McGuigan)	optimal log allocation	RMS-87
RMS-87	NZFP, 1987 (Allison)	forest estate planning and accounting	IFS, NEFDS, LOGRAM

Note: 1. Abbreviations for model developers are as follows:
NZFS - New Zealand Forest Service (HO - Head Office; FRI - Forest Research Institute)
MOF - Ministry of Forestry
NZFC - New Zealand Forestry Council
U of C - University of Canterbury
Tasman - Tasman Forestry Ltd.
NZFP - New Zealand Forest Products

(i) IFS (Garcia, 1981) - the interactive forest simulator described in part 2.1;

(ii) GROHA (Levack and Jennings, 1981) - a set of equations for calculating direct resource flows (jobs, machines, buildings and costs) associated with the growth and harvest of a forest generated by IFS;

(iii) MOVPRO (Lee, 1982) - a simulator for transporting, processing and marketing the resource to satisfy a given regional development scenario, using outputs from IFS; and

(iv) RSUM (Lee, 1981) - a regional summary of all resource flows modelled in the first three steps, along with economic indices for the scenario being modelled.

These models were used for regional planning exercises in Northland and the Central North Island (e.g. CNIPS, 1983). Criticism was levelled at them due to their rigid scenario format, a lack of coherent structure between components, and their non-interactive nature. The database driving the simulations was not transparent to users, and contained no explicit recognition of export/domestic markets nor economic indicators. The system did not allow examination of multiple goals or alternative uses of forest biomass. IFS is the only part of this set of models which is still supported and used.

The Forest Service also developed a linear programming model of the south Westland forestry region in collaboration with the Operations Research department at the University of Canterbury (Eton and George, 1982). This model provided a framework for examining the effect of various resource related options on employment, finance and the future of indigenous forestry on the west coast. It included sub-models for indigenous forest management, exotic forest management, sawmilling and marketing. The database for this model was somewhat weak, and was supported by a number of assumptions regarding future processing and forest management. The only processing option considered was sawmilling, with only one notional market for sawntimber. The model structure does not allow alternative goals to be evaluated simultaneously (this is recognised as a shortcoming by the authors); nor does it allow alternative uses for forest biomass. Nonetheless, the model proved useful for policy analysis during the short time it was actively employed. This model is now obsolete, and the recent moratorium on logging in south Westland has made further development of regional models for that area extremely unlikely.

The Forest Service also supported work on a highly aggregated systems dynamics simulation model known as WOOD2 (Cavana and Coyle, 1984). This model was designed to analyse, at the national level, the interactions between wood supply and demand, with respect to the exotic plantation resource. The model has been used to examine different future demand scenarios, to determine the sensitivity of the New Zealand forestry system to demand forecasting errors, and to analyse national cutting and planting policies. No distinction is made between the policies of State and private sector companies in the model; nor is any distinction made between growth of the old and new radiata pine crops, with average yield curves derived for the entire country. Wood processing is not considered in WOOD2, a potentially serious omission in a model which purports to represent the entire New Zealand plantation forestry system. The model is, however, multi-period, allows different planting and cutting policies, and considers the financial aspects of wood growing. An early version was used by the Ministry of Works and Development for forestry planning, but WOOD2 is also now obsolete.

The Harvesting and Marketing Strategy for State Forest Plantations, or HMS (NZFS, 1985a) was the last "sectoral" planning exercise undertaken by the Forest Service before its dissolution. The objective of HMS was, briefly, to provide likely schedules for the harvesting and marketing of State wood over time, by location, quality and quantity. This document emphasised the Forest Service's changing role, from an active participant in sectoral modelling, to a provider of information for strategic planners in industry (*cf*. Bremner's first strategic planning data requirement listed at the start of Chapter 4). Wood supplies were forecasted for all State forest plantations, region by region, through to 2012. These forecasts were generated via IFS and were based on one scenario of planting, growing and harvesting over the planning horizon. The strategy was to be revised annually, but the breakup of the Forest Service and the concurrent corporatisation of the state forests resulted in the first release of HMS being its last.

The role of HMS has in many ways been filled by the National Exotic Forest Description System (NEFDS) described in section 2.1.2. The New Zealand Forestry Council, under whose auspices the system was developed, inherited the statutory responsibility for forest sector planning from the Forest Service in 1983 and made provision of accurate, timely and comprehensive wood supply statistics a top priority. While the NEFDS does not provide explicit descriptions of wood quality or future quantities available, such data can be generated from its comprehensive inventory statistics using an appropriate forest estate model (e.g. Burrows *et al.*, 1987a). The coverage of the NEFDS (which attempts to include all forest areas greater than one-half hectare) is much more exhaustive than that of HMS. Data capture is improving, with data for almost 80 per cent of the country's plantation area now reported directly by forest owners. The system, updated annually, aims to provide a standardised wood supply data base for all forest sector planners and will hopefully lead to greater consistency and compatibility between models. The NEFDS and the associated responsibility for sectoral planning were transferred to the new Ministry of Forestry in 1987 following the demise of the Forestry Council in late 1986.

The Forest Research Institute has developed models to help the Ministry of Forestry meet its responsibility for sectoral planning. The integrated suite of models developed recently by the Conversion Planning Project Team (CPPT - Kininmonth, 1987) extend the work of two previous FRI task forces: the Mensuration Project Team (Elliott, 1979) and the Radiata Pine Task Force (Sutton, 1982).

The Conversion Planning Project Team was established in 1982, with the objective of producing a modelling system that would help decision makers identify silvicultural and processing options best suited to meeting market requirements for a full range of forest products (Kininmonth, 1982). Figure 2-7 shows the overall model system developed by the CPPT. Cruising assessments, (1), provide indices of tree size and defect, allowing estimates of current wood supply to be generated at the stand level. Stand prediction, (2), provides a means of modelling stand development from any age to final harvest. The supply of various log grades, (3), can then be predicted, based on results from (1) or (2) or both. Single period economic analysis, (4), is then possible, with or without consideration of processing options, (5). The estate models, (6), synthesise results from the other components in an attempt to generate optimal long term forest management strategies. This model system incorporates data from many sources, including conversion studies and market forecasts, often in the form of predictive regression equations. The most important contributions made by the team have been the development of new process simulation models (the sawmill suite and PLYMILL discussed in section 2.1.2), improved forest estate modelling/silvicultural regime comparisons (using IFS/FOLPI in conjunction with STANDMOD/SILMOD - see Table 2-4) and newly proposed national grading rules for radiata pine logs. These rules are a cornerstone of the CPPT's model system and are used to derive log grade aggregations for WPPM; as such they are briefly described here.

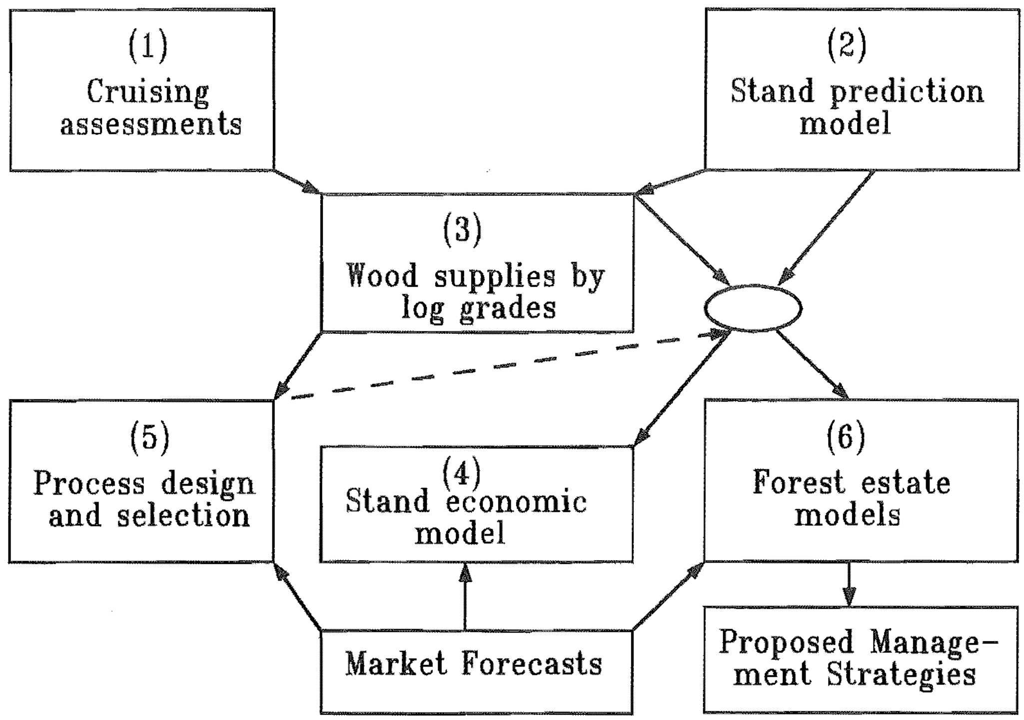

Figure 2-7. Overview of the CPPT model system.
(after Kininmonth *et al.*, 1987)

The proposed radiata pine log grading rules (Whiteside and Manley, 1985) consist of 12 grades distinguished in terms of small end diameter, pruning status, branch size, sweep and internode length (see

Table 2-5). The developers of the rules maintain that national adoption of the grading rules would reduce the variability inherent in the new crop radiata pine resource, guaranteeing standards of uniformity and suitability of raw materials to processors. They further claim that both growers and processors would benefit from enhanced planning if logs were consistently graded as proposed, with growers able to match forest utilisation to market requirements for various log mixes and processors able to link manufacturing options to log mixes to be offered. Strategic planning and modelling would be similarly enhanced by the adoption of such a set of national standards, with forest out-turn easily described in terms of the given grades. However, these advantages may be outweighed by resistance to, and a lack of trust in, the new grading rules by industry, who fear that their introduction would be accompanied by increased wood prices.

Table 2-5. Proposed CPPT log grades.

Grade	Pruned(P)/ Unpruned(U)	Small-end diam.(mm)	Largest branch(cm)	Sweep class[1]	Minimum inter-node index[2]
P1	P	400+	NA	1	NA
P2	P	300-399	NA	1	NA
S1	U	400+	6	1	NA
S2	U	300-399	6	1	NA
S3	P/U	200-299	6	1	NA
S4	P/U	150-199	6	1	NA
L1	U	400+	14	1	NA
L2	U	300-399	14	1	NA
L3	U	200-299	14	1	NA
L4	U	150-199	14	1	NA
I	U	300+	14	1	0.6
R	P/U	100+	NA	2	NA

Notes: 1. Sweep is the maximum deviation from straightness along the length of the log; sweep class is determined by comparing a function of log diameter (dependent on log length) with the maximum sweep present in the log. Sweep class 2 allows eight times more sweep than class 1.
2. Internode index is the sum of lengths of internodes ≥ 0.6 m, expressed as a fraction of total log length.
Source: Whiteside and Manley, 1987.

Other problems have prevented widespread use of the CPPT model system for sectoral planning. Most of the components of the system (with the exception of IFS/FOLPI) deal with single time periods, as pointed out in the discussion of the CPPT process selection model in section 2.1.2. There is no means for examining multiple objectives with the system; indeed, it may be difficult to formulate any *single* objective which is suitable for analysis by all model components. Further problems are outlined by Whyte (1988) and include the imprecision inherent in the multitude of interacting predictive functions used by sub-models such as STANDMOD and SAWMOD. Largely because of these problems, the CPPT system has proven most useful at the single plant level, rather than at the sectoral level. The model system, collectively entitled STANDPAK, has recently been released for sale to industrial and general users. The CPPT was officially disbanded in 1986, but continuing aspects of their work (particularly market research) hold promise for the sector as a whole.

At the University of Canterbury, forest sector modelling has been proceeding since 1981 (Whyte *et al.*, 1981; Baird and Whyte, 1982; Whyte and Baird, 1982 and 1983; Baird and Whyte, 1983; Whyte, 1984; Broad, 1985; Johnson, 1987a, 1987b and 1987c; Baird and Whyte, 1987; Whyte, 1987; Whyte, 1988). Sets of aggregated mathematical programming models, known collectively as FORSEMODEL, are used to characterise and derive strategies for the entire forest sector. FORSEMODEL can aid strategic decisions regarding re-establishment and new planting, harvesting, processing and transport. Questions relating to the demands for capital, energy, labour, and other factors of production can also be addressed. While all parts of the sector are represented in the model, some (such as processing) are represented in a highly aggregated manner. A theoretical approach to modelling some aspects of the processing sector was developed at Canterbury, apart from FORSEMODEL, by Broad (1985). This approach used mixed integer programming and digraph theory to develop optimal wood supply strategies. WPPM (e.g. Johnson, 1987b), described in detail in the following chapter, employs a novel model formulation to attempt to provide a practical planning tool for primary wood processors within the conceptual framework of FORSEMODEL.

The development of FORSEMODEL involved the design of a hierarchical framework which could accept any level of modelling desired by the user and handle it coherently. The national model at the top of the hierarchy can be disaggregated into regional models, which can themselves be decomposed into individual forest models. Despite its potential for strategic planning at a national level, however, the model has only been used for regional analyses thus far. This is due partially to problems in data acquisition and partially to a slowdown in overall model development. Nonetheless, FORSEMODEL is recognised by some (e.g. Leslie, 1986; Hunter, 1986) as the only model that attempts to consider the entire New Zealand forest sector; it is certainly the only representative in Table 2-4 which fully satisfies Nilsson's requirements as listed at the beginning of this section. Results of an application in the Nelson/Marlborough region were reported to the New Zealand Forestry Council (which supported the research) shortly before it was dissolved (Baird and Whyte, 1987). The creation of a new industry/government council, as outlined earlier, could generate renewed interest in this approach to sectoral modelling.

Industry and other agencies have also played a role in advancing forest sector planning in New Zealand. As well as supporting the development of LOGRAM and RMS-87, the New Zealand industry supported an early study by Abel (1973) which used linear programming to assist in strategic plant location decisions. Abel (1977) also carried out an early econometric analysis of the New Zealand sawntimber industry. This model used population projection statistics to forecast domestic lumber demand, but incorporated no consideration of lumber production statistics or export markets. Independent agencies such as the New Zealand Planning Council and the New Zealand Institute of Economic Research have developed a number of broad economy wide models. SDMACRO (Haywood and Cavana, 1986) is a simple systems dynamics model of the New Zealand economy used to forecast trends in macro-economic aggregates (employment, balance of payments, *et cetera*). SDMACRO,together with other general equilibrium models such as JOANNA and JULIANNE (Philpott, 1983), although not detailed enough to plan the development of any single sector, could prove useful to forest sector planners attempting to calibrate and validate their models. Wells and Easton (1986) provide a comprehensive review of the range of such econometric models in New Zealand.

2.3 Summary

A common shortcoming of most of the above forest sector models, and certainly those developed for New Zealand, has been their generalised treatment of wood processing. Elaborate wood supply projections are too often coupled with simplistic representations of the wood using sector, resulting in the generation of equally simplistic strategic alternatives. Models such as PAPYRUS and TAMM alleviate this problem, providing fairly detailed representations of some types of wood processing in their formulations (although the representation of processing costs is identified by Haynes and Adams (1987) as a major shortcoming in most forest sector data bases). However, the econometric nature of these spatial equilibrium models is not particularly well suited to New Zealand. While estimates of demand for and trade in wood products are fairly precise in the USA where these models were developed, the same cannot be said for New Zealand, where demand estimates have been described as "just passable" and trade estimates as "the weak component" (Hunter, 1987). Other problems with the spatial equilibrium approach include severe difficulties in predicting minor trade flows, and more importantly, the inability of the technique to model any objective other than maximising net revenue in the form of producer and consumer surplus (Brooks, 1987). The prime goal of such spatial equilibrium models is to generate trade flows and aggregate estimates of future production/consumption. While such estimates can assist policy planning, it can be difficult (if not impossible) to disaggregate them in reality so as to analyse in detail the effects of such trade on a regional processing industry. Indeed, none of the models discussed above is capable of examining, over a strategic planning horizon, the complex interactions between wood supplies and processing options found in New Zealand with respect to a range of possible objectives. The research reported here presents the mathematical structure and use of a strategic planning model for regional forest planners and wood processors which, if interfaced with appropriate forest sector models, could provide a way to alleviate this shortcoming. The description of its structure begins in the following chapter.

CHAPTER 3

WPPM: A WOOD PROCESSING PLANNING MODEL

The scarcity of strategic planning models emphasising wood processing and marketing in New Zealand has been commented on by several observers (e.g. Leslie, 1986; Hunter, 1987; Whyte, 1987). The lack of attention to these important components of the forestry sector has resulted largely from a pronounced bias towards resource driven planning prevalent throughout the sector until very recently. This bias is beginning to be recognised and in some ways corrected, as can be seen from the work of both the Conversion Planning Project Team at the Forest Research Institute and by the School of Forestry at the University of Canterbury described in Chapter 2. The processing models in the CPPT suite are, however, only single period models (Manley, 1987) with limited value for long range strategic planning. FORSEMODEL, while providing for long range planning, allows only aggregate modelling of processing, with at most ten notional plants allowed in any one region. The other New Zealand models documented in Chapter 2 that incorporate some consideration of wood processing are primarily single period log allocation models, lending support to the claim that "the bulk of forest planning in New Zealand continues to be resource driven" (Whyte, 1987). The recent decision to privatise the State softwood plantations, together with the associated concern of many in the industry with the implications of such a sale on domestic wood availability and prices (Thomson and McElvey, 1988), illustrates the need for a more holistic approach to planning in the forest sector. Such developments may, in combination with the factors mentioned in section 2.2.1, precipitate a new readiness on the part of the forest industry, and forest planners in general, to implement planning methods that give due consideration to all facets of the sector.

The Wood Processing Planning Model (WPPM) described here is the result of efforts to produce a market oriented planning model of particular relevance to the New Zealand wood processing industry, in keeping with the objectives defined in Chapter 1. This chapter outlines the general modelling philosophy adopted in the development of WPPM, details the type of output required from and provided by it, presents the mathematical formulation and discusses several other important features of the model.

3.1 Modelling Philosophy and Background

WPPM has been developed as a framework for aiding decisions in the forest processing industry and, ultimately, in the entire forest sector. The underlying philosophy which has guided its development is one that has been endorsed by many modellers (e.g. Liebman, 1976; Brill *et al.*, 1982;

Bare *et al.*, 1984): the most productive role of such models is to generate and expose alternatives and not necessarily to produce optimal solutions. Thus, the results of a WPPM run are intended to be used as an aid for planners, managers and decision makers, to help them to generate satisfactory strategic plans by providing a means of examining development options arising from alternative assumptions about resources, markets and/or the economy. The type of information which can be provided by the model includes the timing, size and location of new (or shutdown) capacity, the optimal size and concentration of operations, and optimal sales of products by market. This information, documented in detail later in part 3.2, should be used to examine the implications of a particular wood processing development strategy and to form the basis for further post-optimality analyses, rather than being viewed as an operating plan to be immediately implemented.

Acceptance of WPPM's underlying philosophy leads to a number of requirements and related issues. First, the model should be interactive, allowing users to enter and change data and to monitor the solution process. Such a facility is essential if users are to be able to gain the necessary insights to expose and recognise all realistic alternatives. Second, the model should have a minimum of precluding assumptions - users should be able to enter *their* assumptions if the model is to generate meaningful alternatives. Lastly, flexibility in the model structure should allow users with different objectives to generate alternatives appropriate to their own particular emphasis and scale of operations (i.e. single mill vs. regional planning).

Figure 3-1 presents a generalised schematic representation of the scope of WPPM and of the types of issues it has been designed to analyse. Each box in Figure 3-1 will be examined in detail in subsequent sections; the purpose of this diagram is to illustrate the strategic nature of the model. The inter-relationships between industrial strategy and environmental factors are evident, with the industrial structure capable of responding to environmental signals from the economy (cost and availability of labour, energy and capital), markets (price and demand trends plus relevant exchange rate indices) and resources (supplies and quality). Guidelines for streamlining the collection and checking the accuracy of WPPM input data from each of these categories shall be discussed in greater detail in Chapter 4.

The strategic plan of a particular organisation will also depend on its unique technical, financial and personnel resources and capabilities, plus its perceived competitive position in the sector (as discussed in Chapter 2). These factors, essential to strategic planning but beyond WPPM's scope, are portrayed in the broken box in Figure 3-1. It is possible, and even desirable, given the existence of these unique non-modelled factors, that different users of WPPM could develop quite different strategic plans based on the same model results.

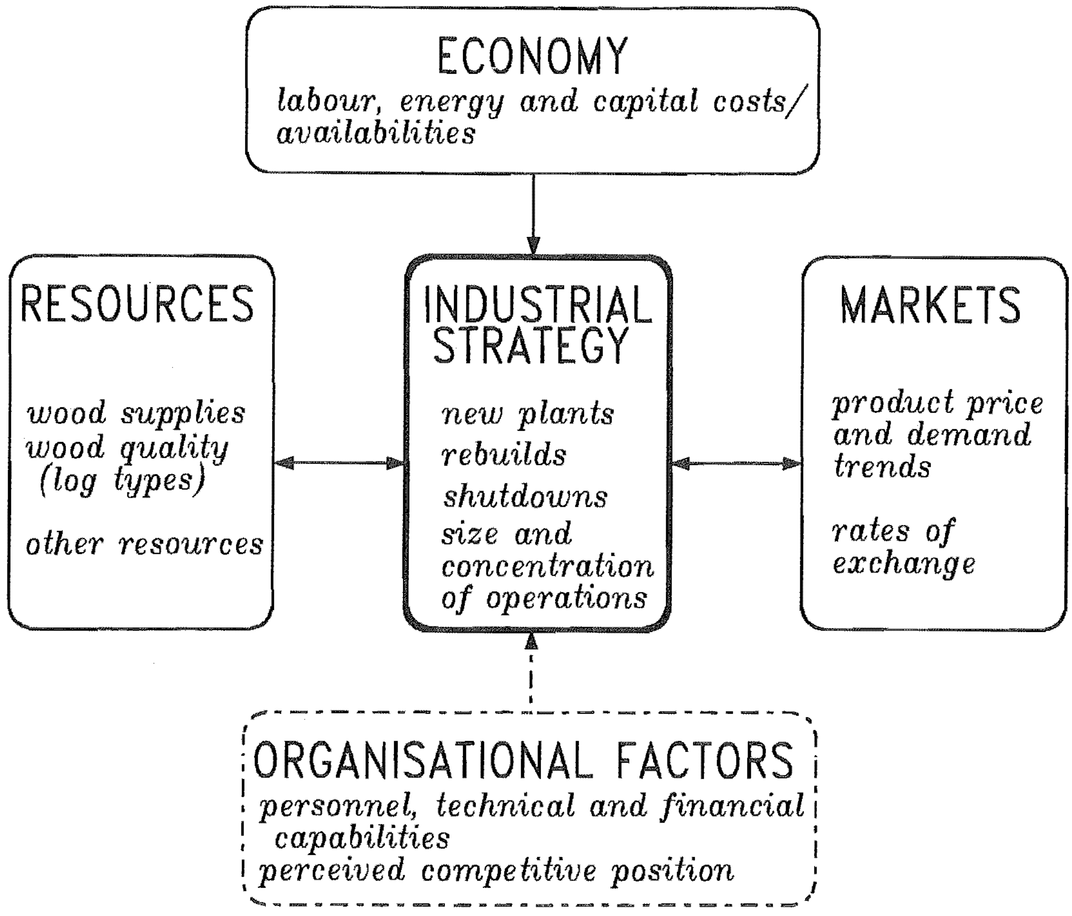

Figure 3-1. Scope and strategic nature of WPPM.

WPPM's ability to generate meaningful strategic alternatives for *all* users arises from the model's formulation (a mixed integer program), its interactive nature (allowing the specification of multiple objectives) and the exploitation of links with other models. The remainder of this part deals with each of these features in more detail.

3.1.1 Mixed integer programming

The numerous production options available to the forest processing sector coupled with myriad resource, manufacturing and market constraints give rise to a planning problem well suited to solution by mathematical programming. The prevalence of mathematical programming (and especially linear programming) models in forest sector applications (described in Chapter 2) is due to the ability of the technique to allocate scarce resources optimally to competing ends without exhaustively examining all such possible allocations. In a large model, the number of total possible allocations can be infinite - hence the preference for a finite solution procedure which can converge to an optimal (or near optimal) solution within an acceptable time span. WPPM employs mathematical programming in the form of a dynamic mixed integer programming (MIP) formulation to model the complex interactions between the forest processing sector, its suppliers of raw materials and its markets over the long time periods that characterise forestry operations.

MIP (and integer programming in general) has not found wide acceptance in forestry. Dykstra (1984, p. 265) listed applications to natural resource management and commented that such applications have been rare. The same conclusion was reached by Bare *et al.* (1984) in their survey of systems analysis in forestry. Examples of MIP in the forestry literature have become more common since these surveys; Melachrinoudis *et al.* (1987) have reported an application to spruce budworm spraying operations in the United States; Fowler and Nautiyal (1986) have implemented a mixed integer model for land use planning in Canada; and Atkins *et al.* (1984) have employed a non-linear integer programming model to address problems in plywood design and manufacture in British Columbia. But overall, forestry applications of the technique remain relatively scarce. Operations research specialists in other disciplines have made wide use of MIP, however, most notably in capacity planning for electricity generation (e.g. Sherali *et al.*, 1987), multi-level distribution problems (e.g. Brown *et al.*, 1987) and in a range of allocation problems (e.g. Van Roy and Wolsey, 1987). The requirement for more realistic planning models in the forestry sector, in tandem with the increasing availability of advanced computer hardware and software technology, will inevitably result in a more widespread acceptance of MIP in forestry applications.

A few of the forest sector models discussed in Chapter 2 have used integer variables to allow a more realistic representation of capacity changes (e.g. Pearse *et al.*, 1984; Kirjasniemi, 1986) but many implement continuous capacity variables of one form or another in their formulations (e.g. Gilless and Buongiorno, 1987; Baird and Whyte, 1987; Kallio *et al.*, 1985). Broad's (1985) theoretical approach for regulating capacity introductions in his "forest utilisation management problems" employed a mixed integer linear programming formulation. Integer variables have also been used in some cases (e.g. Pearse *et al.*, 1984; Baird and Whyte, 1987) to model piece-wise approximations to non-linear supply and demand curves or objective functions.

The inclusion of integer variables in WPPM was deemed necessary to model realistically the discrete changes in capacity which can occur over a strategic planning horizon. While existing production can indeed vary continuously within certain capacity limits, increases and decreases beyond these limits can occur only by rebuilding or shutting down existing plants, or introducing new production capacity. Although integer variables complicate the solution procedure (effectively giving rise to a number of linear programming problems), the SAS software used in WPPM's solution phase is quite capable of handling such problems, since a range of algorithms, designed to minimise solution times, is provided (SAS Institute, 1985).

3.1.2 Interactive modelling

One of the objectives of this research, as stated in Chapter 1, was to produce a model that is realistic and usable in practice. The interactive nature of WPPM, which allows users to enter problems using the best available data and to control the solution procedure and output, is the prime means of attaining this objective.

Users are able to formulate their own specific problems using WPPM's custom built data input program and matrix generator DATMAT (see Chapter 5). This program provides modellers with a great deal of flexibility, allowing models of varying levels of sophistication to be developed and providing flexibility in specifying summaries of model coefficients and parameters to be reported. Existing data sets can be edited using DATMAT with a full screen editor, dispensing with the need to re-enter an entire model when only minor changes are desired. The resulting matrix is in the sparse format required by the SAS solution software. An extension could be developed to provide output in the MPS (mathematical programming system) input format adopted by most other commercial mathematical programming codes (Murtagh, 1981). Such an extension could be programmed relatively easily in the SAS programming language and would enhance the transportability (and hence usability) of WPPM.

DATMAT options facilitate interactive control of the solution procedure, post-optimality analyses, and the generation of output. These options, described in detail in Chapter 5, allow, for example, pausing and then restarting the solution procedure, specifying the level and kind of sensitivity analyses desired, and requesting full or abridged output.

3.1.3 Inter-model linkages

The ability to capitalise on and interact with existing models was considered to be an important aspect in the development of WPPM. Too often, foresters develop models in isolation from each other, with a consequent duplication of effort. They would do well to take heed of a recent warning issued to all modellers by Arnold Reisman (1987) of Case Western Reserve University:

> We [modellers] have seen the details but lost sight of the whole. Our preoccupation may cause our downfall. Instead of developing three more new models, which fit only a certain type and size of problem, we should synthesize the work within our area and through generalization and systemization show its interconnections, inter-relations, and limitations.

This advice helped to guide the development of WPPM, with existing market, processing and/or resource models used to provide relevant data wherever possible. For example, one linkage exploited by WPPM makes use of RMS-87 (Allison, 1987) to generate wood supply schedules by log type, forest and period. Such schedules can be input directly to DATMAT by the user, or can be modified based on local knowledge. The NEFD system described in Chapter 2 can also be used for generating wood supply schedules, either in tandem with RMS-87 (or any of the other forest estate/wood supply models described in Chapter 2 for that matter) or on its own.

A more fundamental philosophical linkage exists between WPPM and FORSEMODEL (Baird and Whyte, 1987), the national forest sector model developed also at the University of Canterbury. WPPM has been formulated to allow integration within the suite of models comprising FORSEMODEL, and, moreover, has adopted many of the philosophies expounded by its developers. These include the provision of interactive model formulation and solution options, a lack of precluding (i.e. built-in) assumptions, flexibility in generating objectives, and the ability to facilitate and incorporate the hierarchical nature of FORSEMODEL. WPPM provides a framework for examining regional wood processing sectors (or individual components thereof) in far greater detail than is possible in FORSEMODEL and would therefore complement its national or regional models. FORSEMODEL could be used to synthesise WPPM results at a national level, selecting amongst competing regions for large scale industrial development for example. It could also provide optimal wood supply schedules to WPPM. Unfortunately, the objective of achieving a practical linkage between these two models has been thwarted by hardware and software incompatability. Further research could produce a version of FORSEMODEL which can implement WPPM solutions on a national scale.

The development of other models in tandem with the further development of WPPM could result in further linkages being explored. Stochastic mill simulation models (e.g. GEMS - Edwards *et al.*, 1987; SAWING - van Wyk and Eng, 1987) could be adapted to provide output on mill costs and recoveries suitable for WPPM. Care would need to be taken to ensure that simulations were conditioned to the types of mills being modelled in WPPM. The development of market models to provide demand curves for various forest products is considered a priority in New Zealand forest research (Kininmonth, 1987). WPPM provides a coherent structure for using data from such models to examine the implications of market forecasts on a regional wood processing industry. These and other potential linkages, when carefully implemented and documented, could serve to enhance the utility and versatility of WPPM to forest industry planners.

3.2 Information Required from WPPM

A primary consideration when defining or describing any model is a description of what type of information the model is expected to provide to the user (Geoffrion, 1976). Such a description can often help to explain the reasoning behind a certain formulation or data requirement and can thus make the model more transparent to the user. The output required from WPPM and the form in which such output is to be provided are documented in the following sections.

3.2.1 Required output

The minimum output required from a WPPM run is summarised in the following list. All results are reported in total (where appropriate) as well as being broken down by product, mill size-class and sub-region (except where otherwise noted). The case study documented in Chapter 6 and Appendix A contains examples of the full range of tabulated output.

- periodic optimal production of final and intermediate products
- periodic optimal allocation of log grades (by supply region)
- periodic importation of logs (by grade) and intermediate/final products
- periodic under-utilised capacity
- periodic changes in capacity (start-ups and shut-downs)
- periodic capital requirements for investment in new capacity
- periodic labour, power and water requirements
- periodic optimal assignment of production and imports to markets (domestic and export)
- summary tables for all the above

Of course, optimal values for the model objective and all variables can also be presented. Such output is a standard feature of the SAS-OR software used to develop WPPM, and of most other commercial mathematical programming packages.

Awareness of the sensitivity of model solutions to changes in key parameters (e.g. changes in prices for raw materials and final products, changes in the availability of inputs to production, changes in market requirements) can lead to valuable insights into the nature of the sector under study and can help to guide future modelling efforts (Williams, 1978). Output from sensitivity analyses of key WPPM variables, constraints and coefficients provides information on changes in production, sales and input requirements resulting from deviations from a given optimal solution. Examples of such analyses (and their output) are presented in Chapter 6.

3.2.2 Output format

Computer solutions of large-scale linear programs generally result in a large volume of rather indigestible output, due to the necessarily general nature of computer mathematical programming packages. The SAS software used here is no exception in this regard. Modellers often lose sight of the difficulty that potential users might have in relating an optimal solution back to the real life problem that gave rise to it. This can result in rejection of the technique or, perhaps more seriously, to abuse of the system through misapplication of results.

The format of the WPPM output discussed above is based on the generalised tabular layout illustrated in Figure 3-2. This tabular format provides an easily assimilable summary of the optimal solutions and sensitivity analyses just described. Output tables are generated from SAS output files by the REPORT module of WPPM, documented in Chapter 5. In addition, full output of the SAS linear programming procedure is available through a DATMAT option.

Table __. Periodic optimal production: "*productname (units)*".[1]

Mill Type[2]	Period 1	2	3	4	...	t
1						
2						
3						
.						
.						
.						
ALL						

Notes: 1. Some tables produced by REPORT will be variations of this structure, depending on the nature of the table.
2. Mill type codes refer to size (e.g. small, medium, large) and location (e.g. N, E, S, W) and are defined by product in DATMAT.

Figure 3-2. Example of WPPM output table format.

3.3 Mathematical Formulation

The following description of WPPM's mixed integer programming formulation assumes an objective of maximising the net return accruing to a regional wood processing industry over a given planning horizon. A regional wood processing industry is defined here as all primary manufacturing enterprises using wood as a raw material (e.g. sawmills, veneer/ply-mills, reconstituted board mills, pulp mills) within the geographical region of interest. This definition includes log and chip export enterprises, but at this stage of model development excludes secondary manufacturers such as furniture, joinery, and treatment plants. The potential for modelling such secondary processing is discussed in Chapter 7.

The above objective would be appropriate for a user (e.g. a consultant or government body) seeking to examine development alternatives for an entire regional wood processing sector, in order to develop a strategy capable of optimising the "common industrial good" (i.e. profit), as in the case study presented in Chapter 6. Alternative objective functions which can be specified with WPPM are discussed in part 3.4, together with a brief indication of the potential for multiple objective and/or goal programming formulations.

The fundamental unit of analysis in WPPM is the "mill type", a notional grouping of mills producing the same product and having certain other characteristics in common (capacity, location, log/product transport costs, production costs, *et cetera*). The stratification of mill types by capacity allows economies of scale for the various production processes to be explicitly modelled, albeit in a stepwise rather than a continuous fashion. Mill types can consist of one or many individual mills, each possessing the characteristics of an average mill in its class. In regional analyses such as those in Chapter 6, estimates of the number of actual mills making up a mill type can be derived by dividing the total available capacity for that mill type by its capacity change parameter (usually the minimum capacity necessary to realise economies of scale for mills in that class). Figure 3-3 illustrates the concept of mill type in a simplified representation of the type of interactions modelled by WPPM in each period.

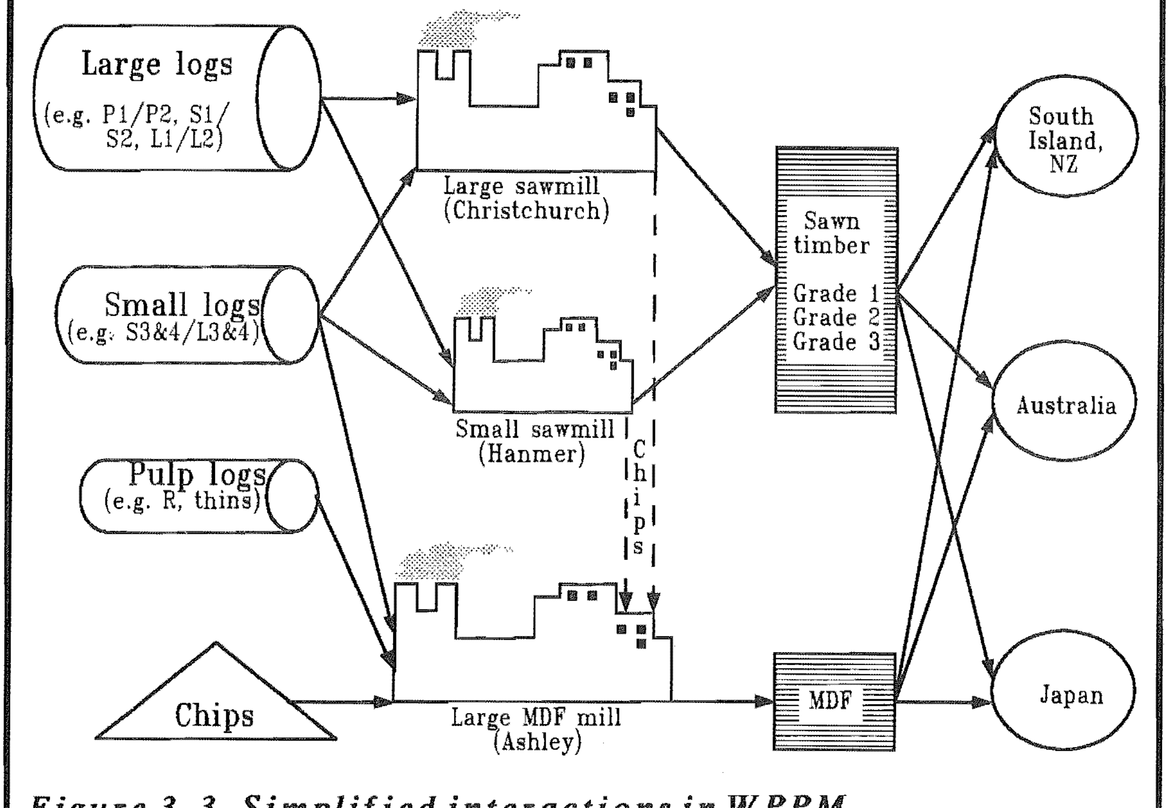

Figure 3-3. Simplified interactions in WPPM.
Note: see Table 2-5 for definitions of log quality class codes.

WPPM is defined in Table 3-1 (and the following equations/ constraints) in terms of its constituent sets, indices, decision variables and parameters. The generalised mathematical equations following this table specify the model objective function (as described above) and many of the production constraints faced by the wood processing industry. A detailed commentary accompanies each such equation, describing its function and any limitations or special features it has. The objective function and constraints presented will hereafter be referred to as the WPPM base model, as any user modifications will be departures from this basis.

Table 3-1. Description of WPPM sets, indices, decision variables and parameters.

Symbol	Definition
Sets	
CF	the set of all final products
CI	the set of all intermediate products
CL	the set of all log grades
CO	the set of all non-wood inputs to production
N	the set of all wood products ($CI \cup CF$)[1]
I	the set of all commodities ($N \cup CO \cup CL$)
F	the set of all forest supply sub-regions
IS	the set of all import source regions
MR_n	the set of all sub-regions for location of existing and/or potential mills producing product $n \in N$[2]
MS_n	the set of all mill sizes producing product $n \in N$
MT_n	the set of all mill types (defined by MR_n and MS_n) producing intermediate or final product $n \in N$
OS	the set of all non-wood commodity sources
J	the set of all commodity sources ($MT_n \cup F \cup IS \cup OS \quad \forall\, n \in N$)[3]
D	the set of all domestic markets
E	the set of all export markets
K	the set of all commodity sinks ($MT_n \cup D \cup E \quad \forall\, n \in N$)
T_a	the set of all annual time periods
T_o	the set of all other (non-annual) time periods (all are of equal length - 5 years - in the base model)
T	the set of all time periods considered in the planning horizon ($T_a \cup T_o$)
Indices	
i, n	commodities (logs; intermediate, final or non-wood products)
j	commodity source (forest, mill, import or non-wood sources)
k	commodity sink (mills or markets)
t	time period (annual or non-annual periods)
Decision variables	
$\alpha_{k(n)t}$	integer variable allowing capacity additions for mill type $k \in MT_n$ in period $t \in T$[4]
$\beta_{k(n)t}$	integer variable allowing capacity shut downs for mill type $k \in MT_n$ in period $t \in T$
$m_{ijk(n)t}$	quantity of imports of commodity $i \in N \cup CL$ to mill type $k \in MT_n$ from source $j \in IS$ in period $t \in T$
p_{nkt}	production level for $n \in N$ in mill type $k \in MT_n$ in period $t \in T$
$q_{ik(n)t}$	quantity of commodity $i \in N \cup CL$ stored at mill type $k \in MT_n$ in period $t \in T$
x_{ijkt}	quantity of commodity $i \in I$ from source $j \in J$ utilised in (sold to) sink $k \in K$ in period $t \in T$

Notes: 1. The symbol "$\cup$" in "$CI \cup CF$" signifies union between sets (i.e. N contains all of the elements of both CI and CF).

2. The symbol "$\in$" in "$n \in N$" signifies that the index n belongs to (and can assume all possible values of) set N.

3. The symbol "$\forall$" in "$MT_n \cup F \cup IS \cup OS \ \forall\, n \in N$" is defined as "for all", signifying that all possible values of n are to be considered.

4. The index "k(n)" in this and all following expressions is used to indicate that the number of possible mill types (defined by size class and location) varies with product. For the sake of brevity in the subscripting of variables in the objective function and constraints, the "(n)" may be omitted.

Table 3-1. (cont.)

Symbol	Definition
Parameters[5]	
$A_{k(n)t}$	the upper bound on capital availability to mill type $k \in MT_n$ in period $t \in T$
$C_{k(n)}$	the base year capacity of mill type $k \in MT_n$
D_{nkt}	the bound(s) (upper and/or lower) on market $k \in D \cup E$ requirement for product $n \in N$ in period $t \in T$
$L_{ijk(n)t}$	the upper (lower) bound on non-wood input $i \in CO$ available to (required from) mill type $k \in MT_n$ from source $j \in OS$ in period $t \in T$
$M_{ijk(n)t}$	the upper bound on imports of commodity $i \in I$ available to mill type $k \in MT_n$ from source $j \in IS$ in period $t \in T$
P_{it}	the upper bound on export port capacity for commodity $i \in N \cup CL$ in period $t \in T$
W_{ijt}	the upper bound on availability of log type $i \in CL$ from forest sub-region $j \in F$ in period $t \in T$
b_{ijkt}	the revenue associated with selling one unit of commodity $i \in N$ from source $j \in MT_l \cup F \cup IS$ to sink $k \in K$ in period $t \in T$
c_{inkt}	the input (output) of commodity $i \in CI \cup CO$ required for (resulting from) production of one unit of $n \in N$ at mill type $k \in MT_n$ in period $t \in T$
f_i	the allowable storage fraction of commodity $i \in N \cup CL$
g_i	the allowable import fraction of commodity $i \in N \cup CL$
$h_{k(n)}$	the capacity change step size of mill type $k \in MT_n$
i^o	the real rate of interest[6]
Θ_t	length of time period $t \in T$ in years (subscript may be omitted)
Φ	factor for determining the net worth of a series of Θ_t annual costs and revenues at the beginning of non-annual period $t \in T_o$[7]
r_t	factor for discounting periodic revenues and costs to base year[8]
$s_{ik(n)t}$	the cost of storing one unit of commodity $i \in N \cup CL$ at mill type $k \in MT_n$ in period $t \in T$
$\tau_{k(n)}$	an annuity factor to obtain annual cash flows required to offset depreciation and capital costs associated with mill type $k \in MT_n$[9]
φ_t	the exchange rate index for period $t \in T$ (see constraint 2.10)
$u_{k(n)t}$	the revenue associated with closing down mill type $k \in MT_n$ in period $t \in T$ (liquidation revenue)
$v_{k(n)t}$	the capital cost of building mill type $k \in MT_n$ in period $t \in T$
w_{inkt}	the output of $n \in N$ resulting from input of one cubic metre of log type $i \in CL$ to mill type $k \in MT_n$ in period $t \in T$
$y_{ijk(n)t}$	the cost associated with utilising one unit of commodity $i \in I$ from source $j \in J$ at mill type $k \in MT_n$ in period $t \in T$

Notes: 5. Parameters beginning with an upper case letter represent constraint right-hand side values; those in lower case symbolise left-hand side technological coefficients for the objective function and constraints.

6. All interest and discounting formulae presented in Table 3-1 have been adapted from Davis and Johnson (1987) and Dykstra (1984). The real rate of interest is defined as the nominal rate (i) adjusted for inflation ($e > 0$) or deflation ($e < 0$) and is calculated as:

$$i^o = (1 + i)/(1 + e) \tag{6a}$$

7. All cost and revenue figures in WPPM are assumed to be annual and are earned (incurred) at the end of the year. In non-annual periods, the given costs and revenues are assumed to hold for each year in the period. The factor Φ is used to discount each of these annual net incomes back to the beginning of the non-annual period and to sum these to obtain a discounted figure for the entire period.

$$\Phi = \sum_{\delta=1}^{\Theta} (1 + i^o)^{-\delta} \tag{7a}$$

8. Once all periodic costs and revenues have been discounted back to the beginning of each non-annual period via Φ, they must then be discounted back to the base year of the analysis. Annual periods are discounted via (8a). The formula for non-annual periods, (8b), requires a correction factor (4z in this case) for the number of annual periods (z) in the planning horizon. This approach requires Θ_t to be constant $\forall t \in T_o$. The value of 4z corresponds to $\Theta_t = 5 \ \forall t \in T_o$. If $\Theta_t = 10 \ \forall t \in T_o$, the correction factor becomes 9z.

$$r_t = \begin{cases} (1 + i^o)^{-t} & \forall t \in T_a \quad (8a) \\ (1 + i^o)^{[-(t-1)\Theta + 4z]} & \forall t \in T_o \quad (8b) \end{cases}$$

9. The annuity factor is calculated as follows where "λ" is the lifetime (in years) of mill type $k \in MT_n$:

$$\tau_{k(n)} = \frac{[i^o(1 + i^o)^{\lambda}]}{[(1 + i^o)^{\lambda} - 1]} \tag{9a}$$

3.3.1 Objective function

Equation (1) states the objective assumed for the base model: the maximisation of net profit to a regional wood processing industry. Other relevant modelling objectives are examined in part 3.4.

Maximise:

$$Z = \sum_{t \in T} r_t[\Phi(R_t - LC_t - PC_t - SC_t - TC_t - CC_t + S_t)] \tag{1}$$

Where:

$$R_t = \sum_{i \in N} \sum_{j \in MT_i} \sum_{k \in K} b_{ijkt} x_{ijkt} \tag{1.1}$$

= the total annual gross revenue accruing during period t to all mill types j from sales of all intermediate and final products i to market or mill type k.

$$LC_t = \sum_{i \in L} \sum_{k \in MT} \left[\sum_{j \in F} y_{ijkt} x_{ijkt} + \sum_{j \in IS} y_{ijkt} m_{ijkt} \right] \tag{1.2}$$

= the total annual cost of local and imported wood supplies for all log types i sent from forest region or import source j to mill type k during period t.

$$PC_t = \sum_{i \in C} \sum_{n \in N} \sum_{j \in S_i} \sum_{k \in MT_n} y_{ijkt} c_{inkt} p_{nkt} + \sum_{i \in NO} \sum_{j \in IS} \sum_{k \in MT} y_{ijkt} m_{ijkt} \tag{1.3}$$

= total annual production costs, incorporating (a) the cost of intermediate and non-wood input i ($i \in C \equiv CI \cup CO$) from source j ($j \in S_i \equiv MT_{i \in CI} \cup OS$) used in the production of all intermediate or final products n in mill type k during period t; plus (b) the cost of all final, intermediate and non-wood products i ($i \in NO \equiv N \cup CO$) imported from source j to mill type k during period t. Note that import product i can only be sent to mills that actually manufacture (or use) that product, as ensured by constraint (2.15).

$$SC_t = \sum_{i \in NL} \sum_{k \in MT} s_{ikt} q_{ikt} \tag{1.4}$$

= the total annual cost of storing commodity i ($i \in NL \equiv N \cup CL$) at mill type k during period t. As above, only mills manufacturing or using commodity i are allowed to store it (ensured through constraints (2.12) - (2.14)). This element of the objective function is only specified if storage costs vary with the quantity stored, and only for $t \in T_a$ in the base model.

$$TC_t = \sum_{i \in N} \sum_{j \in MT_i} \sum_{k \in M} y_{ijkt} x_{ijkt} \tag{1.5}$$

= the total annual cost of transporting intermediate or final product i from mill type j to market k ($k \in M \equiv D \cup E$) during period t. If sales are FOB, TC incorporates transport, wharfage and port handling charges; if CIF, it will also include insurance and freight charges.

$$CC_t = \sum_{k \in MT} \tau_k v_{kt} \alpha_{kt} \tag{1.6}$$

= the total annual capital cost (including depreciation) of building α type k mills during period t.

$$S_t = \sum_{k \in MT} u_{kt} \beta_{kt} \tag{1.7}$$

= the total annual revenue resulting from shutting down (and liquidating the assets of) β type k mills during period t.

3.3.2 Constraints

The following constraints represent several factors identified as having a significant limiting effect on operations by wood processing companies surveyed during the course of this research. Although WPPM allows for the flexibility of user defined constraints (see Chapter 5), those listed here (and included in the base model) should suffice for most applications.

(1) Wood supplies.

(i) Local wood availability

$$\sum_{k \in K} x_{ijkt} \leq W_{ijt} \qquad \forall\, i \in CL,\ j \in F,\ t \in T \tag{2.1}$$

The total amount of type i logs transferred from forest supply sub-region j to all sinks k (mills and/or markets) in period t must not exceed the maximum supply of such logs available from that sub-region in the given time period.

(ii) Imported wood availability

$$\sum_{k \in K} m_{ijkt} \leq M_{ijt} \qquad \forall\, i \in CL,\ j \in IS,\ t \in T \tag{2.2}$$

The total amount of type i logs imported from import source region j to all sinks k (mills and/or markets) in period t must not exceed the maximum supply of such logs available from that source in the given time period. Log "speculation" (importing logs only to export them once again unprocessed) can be avoided in WPPM by restricting the summation to $k \in MT$ in constraint (2.2).

(2) Resources limiting production.

(i) Wood material balance

$$\sum_{i \in CL} w_{inkt} \left[\sum_{j \in F} x_{ijkt} + \sum_{j \in IS} m_{ijkt} + q_{ik(t-1)} - q_{ikt} \right] - p_{nkt} \geq 0$$

$$\forall\, n \in N,\ k \in MT_n,\ t \in T \tag{2.3}$$

The production of intermediate or final product n at mill type k during period t is limited by the wood available for that process (local, imported and stored) and the associated conversion factor. Note that the storage of logs is only allowed between successive *annual* periods in the base model. Wood supplies are assumed to be non-transferable between non-annual periods and the storage variables drop out for periods $t \in T_o$. Constraint (2.3) is expressed as an inequality to allow for the less than complete utilisation of wood supplies, a situation that could arise in a multi-product mill if one product to be produced from a given supply of logs were profitable while others were not.

(ii) Non-wood bounds

$$\sum_{n \in N} c_{inkt} p_{nkt} \leq (\geq)\ L_{ikt} \qquad \forall\ i \in CO,\ k \in MT_n,\ t \in T \quad (2.4)$$

The consumption (generation) of non-wood input (output) i (water, power, employment, pollution, *et cetera*) in the production of all products n at mill type k during period t must/must not exceed the amount of the input available to (output allowed or required from) that mill type. Imports of non-wood inputs are not considered in the base model.

(iii) Intermediate products material balance

$$\sum_{n \in CF} \sum_{k \in MTn} c_{inkt} p_{nkt} - \sum_{k \in MT} p_{ikt} - \sum_{j \in IS} \sum_{k \in MT} m_{ijkt} \leq 0 \qquad \forall\ i \in CI,\ t \in T \quad (2.5)$$

The amount of intermediate product i used by all mill types k in the manufacture of all final products n during period t must not exceed total production plus total imports of that intermediate product by all mills.

(iv) Capital availability

$$\alpha_{kt} v_{kt} \leq A_{kt} \qquad \forall\ k \in MT,\ t \in T \quad (2.6)$$

The capital cost of building mill type k in period t must not exceed the capital available to that mill type. If capital availability for the industry as a whole cannot be broken down into amounts available to each mill type, the left-hand side of constraint (2.6) can be summed over k to give the industry wide capital requirement. Note that the capital requirement for building a mill in a given period must be met in that period, even though the required capital may take the form of a long term loan. This constraint ensures that the required capital is indeed available - the depreciation of the resulting mill and any related interest charges are accounted for in the objective function.

(3) Capacity limits.

(i) Capacity change

$$\sum_{n \in N} p_{nkt} \leq C_k + \sum_{t'=1}^{t-1} h_k \alpha_{kt'} - \sum_{t'=1}^{t} h_k \beta_{kt'} \qquad \forall\ k \in MT,\ t \in T \quad (2.7)$$

The total production of all products n at mill type k in period t must not exceed the aggregate starting capacity for all products at that mill type, plus the sum of all additions to capacity in periods previous to the current one, less the sum of all capacity shutdowns in the current period and all previous ones. Constraint (2.6) ensures that there is a one period lag in the start-up of new capacity, assuming that one year is spent on construction and start-up prior to achieving full production levels. For non-annual periods ($t \epsilon T_o$), this lag is not considered and the final two terms in constraint (2.7) can be grouped within a single summation as follows:

$$\sum_{t'=1}^{t} h_k(\alpha_{kt'} - \beta_{kt'}) \tag{2.7a}$$

(ii) Integer capacity variables

$$\alpha_{kt}, \beta_{kt} \text{ integer only.} \qquad \forall\, k \in MT_n,\ t \in T \quad (2.8)$$

The capacity change variables are restricted to integer values (i.e. 0, 1, 2, 3). The number of integer values these variables are allowed to take determines the number of independent capacity additions or shutdowns allowed per period. As solution time for the resulting model increases rapidly with the number of such values, it is recommended that no more than 3 changes per period be allowed.

(4) Market requirements.

(i) Domestic bounds

$$\sum_{j \in MT_n} x_{njkt} \geq (\leq)\ D_{nkt} \qquad \forall\, n \in N,\ k \in D,\ t \in T \quad (2.9)$$

(ii) Export bounds

$$\sum_{j \in MT_n} x_{njkt} \geq (\leq)\ f(\varphi_t) D_{nkt} \qquad \forall\, n \in N,\ k \in E,\ t \in T \quad (2.10)$$

The total quantity of final product i sold from all type j mills manufacturing it for market k must (must not) exceed the minimum (maximum) demand of that market in period t. For export markets ($k \in E$), the minimum market requirement can be expressed as a product of the forecasted demand and a function of the predicted exchange rate index in the given period, $f(\varphi_t)$. The exchange rate index used in the case study in Chapter 6 is a composite developed by the Reserve Bank of New Zealand (1988), incorporating weighted exchange rates for New Zealand's five major trading partners (Australia, Japan, USA, UK and West Germany). A simple example of such an exchange rate function is derived in Chapter 6; procedures for obtaining estimates of market bounds are detailed in Chapter 4.

(5) Miscellaneous.

(i) Product material balance

$$\sum_{k \epsilon K} x_{njkt} + [q_{njt} - p_{njt} - m_{njt} - q_{nj(t-1)}] = 0 \ \forall\ n \epsilon N, j \epsilon MT_n, t \epsilon T \quad (2.11)$$

The quantity of product *n* sold to sink *k* (or stored) by each type *j* mill manufacturing it in period *t* must equal the quantity produced plus the quantity imported in that period, plus storage remaining from the previous period. For non-annual periods ($t \epsilon T_o$), the storage terms are optional.

(ii) Storage limits

Logs:

$$q_{ikt} \leq \sum_{j \epsilon F} f_i x_{ijkt} \qquad \forall\ i \epsilon CL, k \epsilon MT, t \epsilon T_a \quad (2.12)$$

Final products:

$$q_{ikt} \leq f_i p_{ikt} \qquad \forall\ i \epsilon CF, k \epsilon MT_i, t \epsilon T_a \quad (2.13)$$

Intermediate products:

$$q_{ikt} \leq \sum_{j \epsilon MTi} f_i x_{ijkt} \qquad \forall\ i \epsilon CI, k \epsilon MT, t \epsilon T_a \quad (2.14)$$

These constraints limit storage to a fraction *f* of delivered logs, production or delivered intermediate products as the case may be. While the absolute level of *f* can be varied (the base model provides a single value of 10 per cent for *f*), the primary purpose of these constraints is to ensure that there is no storage of a commodity in mills where none has been shipped or produced. Imports are not included on the right-hand sides of these constraints; it is assumed that all commodity imports are used to meet demands in the current period.

(iii) Product imports

$$\sum_{j \epsilon IS} m_{ijkt} \leq g_i p_{ikt} \qquad \forall\ i \epsilon N, k \epsilon MT_i, t \epsilon T \quad (2.15)$$

These constraints limit imports of final and intermediate products to a fraction *g* of production. As above, the level of *g* can be varied, the prime purpose of these constraints being to prevent imports to non-producing mills. Note that for $i \epsilon CI$ (intermediate products), $k \epsilon MT_i$ in constraint (2.15) refers to mills producing and/or using product *i*. Log imports were explicitly constrained in constraint (2.2); explicit constraints can also be generated to replace (2.15) if data on actual upper bounds for product imports exists.

(iv) Export port capacity

$$\sum_{j \epsilon MT} \sum_{k \epsilon E} x_{ijkt} \leq P_{it} \qquad \forall\ i \epsilon N \cup CL, t \epsilon T \quad (2.16)$$

Total exports of log grade or forest product i are limited to the region's available export port capacity for commodity i in period t. Note that log exports are only allowed via mills in constraint 2.16 - this restriction can be relaxed if the model is adapted for independent forest owners.

3.4 Alternative Modelling Objectives

The base model just defined takes profit maximisation to the industry as a whole as its objective, corresponding to one possible goal of users such as the Ministry of Forestry and Regional Planning Authorities. Clearly, the objective(s) of a small private mill owner will differ from that of a public agency such as MOF, which will in turn differ from that of a large pulp and paper corporation. WPPM allows users to construct their own objective functions, giving the model considerable flexibility to a range of users.

Examples of objectives which can be specified include maximising employment levels for a region (or minimising redundancies), maximising foreign exchange earnings, maximising value added in manufacturing, minimising capital requirements, minimising imports, minimising water (or any other input to production) usage, and maximising returns to a single mill type or group of mill types. Another objective of interest (particularly to government bodies) might be to maximise the forest processing sector's contribution to gross regional product (GRP) over the planning horizon. GRP is defined as the total value at current prices of the goods produced and services rendered (including exports) by the people and enterprises of a region during a given time period (after Ford-Robertson, 1971). Such an objective is formulated by removing wages, costs for raw materials originating within the sector (i.e. wood), and interest costs from the base model objective.

All of the above objectives, and any others which can be formulated in terms of WPPM's decision variables, are potential candidates for modelling. This clearly leads to a large number of potential objective functions and thus a requirement for rational selection. Users should take care to ensure that any objective formulated is consistent with their goals.

WPPM allows specification of up to ten different objective functions, with the model re-solved for each. This can save considerable data entry time if different objectives are being evaluated. It is likely that many users will utilise this multiple objective facility, since strategy formulation can encompass a number of different (and perhaps conflicting) goals, as discussed in Chapter 2. The computational task of re-solving the model for different objectives is eased by using the solution to each problem as the starting point for the next. This is facilitated by specifying special options in the solution procedure (see Chapter 5).

Re-solving for different objectives is, however, a rather cumbersome way of solving multiple objective problems, and further development of WPPM could result in a more elegant facility for handling such problems. Multiple objective mathematical programming (MOMP - e.g. goal programming, multiple objective linear programming) provides a tool for solving such problems, and has been receiving substantial attention in the forestry literature. Recent work has included applications to forest land management planning in the USA (Bare and Mendoza, 1988), to multiple use planning in a New Zealand forest park (Whyte and Daellenbach, 1987), and to the planning and evaluation of agroforestry systems (Mendoza *et al.*, 1986). FORSEMODEL (e.g. Whyte and Baird, 1982) incorporates MOMP algorithms in its formulation, but has not yet been used to solve multi-criteria problems (Baird and Whyte, 1987).

The extension of WPPM to allow explicit generation and solution of multiple objective problems will be fairly straightforward for users running SAS on mainframe computers which support the SAS Macro Language (SAS Institute, 1985). Cohen (1984) has developed a goal programming macro ("GOALPROG") using this language and SAS-OR. His approach, based on the work of Ignizio (1983) and Zeleny (1982), requires that each objective be ranked according to the modeller's priorities. A linear program is then solved for each objective, starting with the highest priority objective and ignoring all others. The second priority objective is then optimised, subject to an additional constraint which prevents the first from being degraded (GOALPROG allows for a user specified relaxation in previously obtained objective levels). This process continues until all objectives have been optimised. Unfortunately, the SAS Macro Language and the SAS Macro Library (containing GOALPROG) have not yet been implemented on mini-computers (including the Vax 6210 computer at the University of Canterbury). When and if they are, this macro could be interfaced with WPPM to provide a built in MOMP facility for users operating on such systems.

3.5 Model Size Considerations

The WPPM base model, defined in Table 3-1 and in the following chapters, can consist of up to 10 000 decision variables and 4 000 constraints, depending on the number of mill types, products, periods, *et cetera* to be modelled. Model dimensions can be varied by extending or reducing the base model, with the only limit on model size being available computer memory. However, as model size grows beyond that allowed in the base model, or as base model solutions for different regions are amalgamated to seek a national strategy (e.g. by FORSEMODEL), techniques for reducing model size and computation time will be required. Two such techniques are considered here: decomposition and recursive programming.

3.5.1 Decomposition

As with most large linear programs, WPPM has a high degree of structure. This structure results from the similarity of constraints affecting each of the different mill types (defined by product, size and location), and gives rise to the block angular (or block diagonal) matrix depicted in Figure 3-4. The common constraints are those that are binding on all mill types throughout a region and include wood supply, market requirement and linking constraints from section 3.3.2.

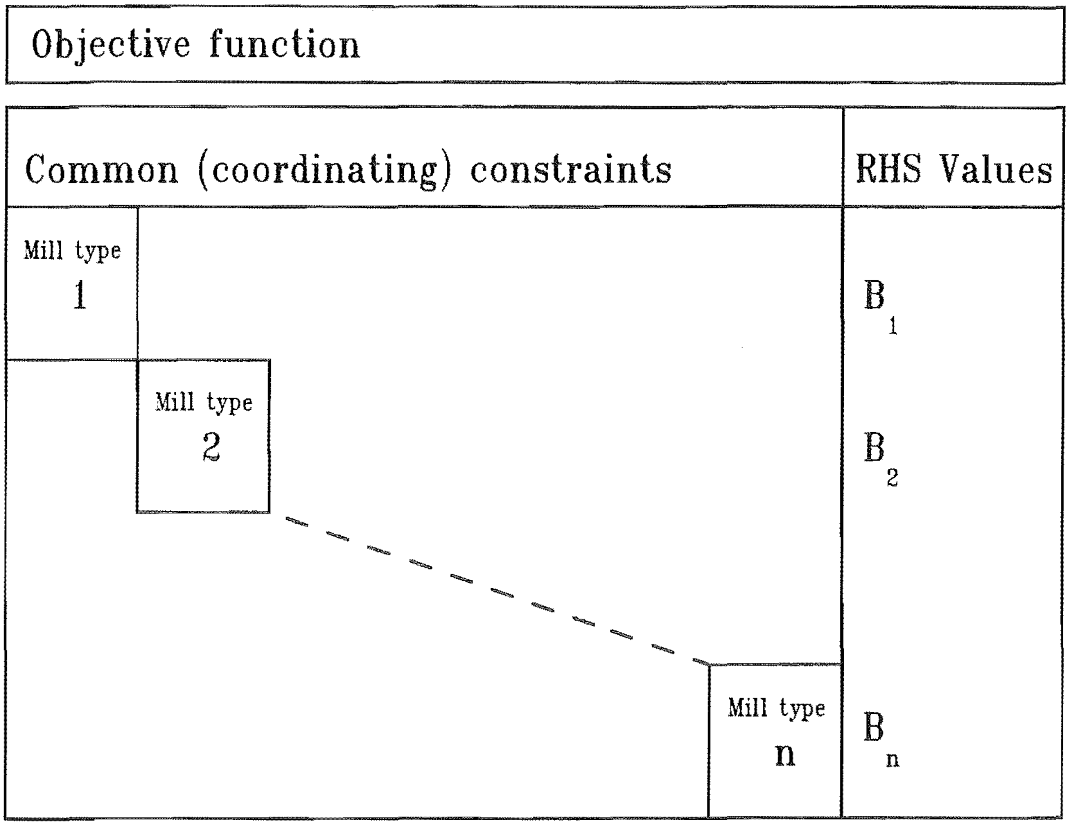

Figure 3-4. Block angular structure in WPPM.

Several specialised solution algorithms exist which take advantage of the type of structure shown in Figure 3-4 to reduce problem size and, as a result, computer memory requirements. Such algorithms, collectively known as decomposition techniques, operate on the principle that the optimal solution to a large, structured model should bear some relation to the optimal solutions for its components or submodels (the blocks in Figure 3-4). The most well known of such techniques is Dantzig-Wolfe (D-W) decomposition (Dantzig and Wolfe, 1960). The D-W algorithm forms a "master problem" with only a few more rows than there are common constraints in the original problem, but with many more columns (one new variable for each basic feasible solution of each submodel). Fortunately, most of these additional variables will never enter a solution to the master problem, so the model is solved by adding columns only when the associated variable contributes to an improvement in the objective function. This technique, known as column generation (Lasdon, 1970), is relatively common in mathematical programming (Williams, 1978). It gives rise to the computational savings associated with decomposition, with only part of the problem stored in computer memory at any one time.

The D-W algorithm proceeds by iterating between the independent submodels (which receive "prices" associated with the common constraints from the master problem) and the master problem (which receives optimal solutions from each submodel, combines them with previous optima and generates new "prices" for the submodels). The process reaches optimality for the overall problem when no submodel can find an optimal solution that is not already incorporated in the master problem.

The use of prices in the D-W algorithm has led to its being assigned labels such as price-coordinated or transfer pricing decomposition (Burton *et al.*, 1974). Economists (e.g. Baumol and Fabian, 1964) were quick to see the analogy between price-coordinated decomposition and systems of decentralised planning, equating submodels to separate divisions of a large organisation (the master problem) which attempts to coordinate their use of shared resources to maximise the common good. This interpretation is easily extended to the WPPM base model, with mill types as divisions and the regional government or Ministry of Forestry attempting to coordinate these "divisions" to maximise the regional good, defined by net profit to the regional industry.

Most forestry applications of decomposition have been concerned with harvest scheduling problems and, although few in number, have kept pace with developments in this field of mathematical programming. Littschwager and Tcheng (1967) solved a relatively simple scheduling problem using D-W decomposition. Caswell and Rao (1974) reformulated the same problem as a transportation problem, however, and obtained the optimal solution 40 times faster using a specialised network algorithm. Williams (1976) used a Dantzig-Wolfe approach to integrate stand and forest models while Nazareth (1980) used the technique in combination with dynamic programming in a land management model. The real-time pulp blending and scheduling model discussed in Chapter 2 (Hara *et al.*, 1987) uses D-W decomposition to reduce memory requirements and computer processing times, allowing optimal production schedules to be produced every eight hours on a 32 bit mini-computer. Other applications have employed variations of the D-W algorithm: FORSEMODEL (Whyte and Baird, 1982; Baird, 1981 and 1982) employed pricing heuristics in its column generation technique; Garcia (1984) discussed the possibility of a D-W decomposition for FOLPI wherein the submodels could be reduced to easily solved networks; Berck and Bible (1984) utilised the dual of their harvest scheduling problem (essentially the mirror image of the primal problem) in a Dantzig-Wolfe approach, cutting solution time in half; and both Hoganson and Rose (1984) and Gunn and Rai (1987) have used the concept of "Lagrangian duality" to incorporate certain constraints from their harvest scheduling problems within the objective functions, thus decomposing the problems and improving solution times.

Since different users of WPPM will produce models of varying size and complexity, the decision to implement a decomposition technique will rest with the user after suitable consultation with model developers or operations research specialists. This decision should be based on the size of the problem and its computational tractability, remembering that multiple runs may well be necessary to provide a full range of alternative solutions and sensitivity analyses. Such multiple runs may not be feasible (in terms of computer resources) for very large models without employing some type of decomposition approach. However, since all decomposition techniques take advantage of the special structure of the underlying model, some of the flexibility associated with WPPM (i.e. the ability to change its structure by adding constraints or variables) may be lost if a decomposition approach is developed based on a particular model structure. As the size of the base model is considered marginal at best in terms of the utility of decomposition (Baird, *pers. comm.* 1988), and since non-decomposed solution times are reasonable (see Chapter 7), the development of specialised decomposition algorithms for WPPM was not undertaken. Further work could lead to such a development, most probably along the lines of the FORSEMODEL decomposition algorithm, particularly if the base model is expanded to encompass more products as discussed in Chapter 7. In order to program and interface any decomposition algorithm with the existing model (remembering the iterative nature of decomposition and the absence of any explicit decomposition algorithms from the SAS-OR product), it will be desirable to have access to the SAS Macro Language.

3.5.2 Recursive programming

Recursive programming involves removing the time dimension from a model and re-running it for each period in the planning horizon. Each succeeding run is preceded by an update of model coefficients and parameters, based on the optimal result for the previous period. The technique, originally developed by Day (1973), was applied to IIASA's GTM (Dykstra, 1986) and to the spatial equilibrium model of the North American pulp and paper industry developed by Gilless and Buongiorno (1987). Recursive programming has two main advantages: it does not assume perfect foresight on the part of decision makers (e.g. in the prediction of market demands) and it reduces the size of the problem by a factor approximately equal to the number of periods in the planning horizon. The danger in its application to WPPM is that, since the problem is not solved for the whole planning horizon at once, time profiles of, for example, the optimal depletion rate of wood supplies and and the optimal growth or decline in processing capacity cannot be determined. Nonetheless, the application of recursive programming to WPPM could be considered in future, either alone or in combination with decomposition, to make large problems manageable. The development of the updating programs would again be greatly facilitated by the availability of the SAS Macro Language.

This chapter has presented the general structure and philosophy of WPPM (including multiple objective and model size considerations), as well as the type and format of output to be provided by it. Chapters 4, 5 and 6 extend this general discussion, focussing on input data requirements (Chapter 4), model documentation (Chapter 5) and a case study (Chapter 6) that addresses many of the concepts presented here and illustrates the potential of the modelling system.

CHAPTER 4

DATA REQUIREMENTS

The utility of a model such as WPPM is clearly dependent on a number of factors: these include requirements of the user, the chosen problem formulation and associated objective functions, the appropriateness of underlying assumptions and, of course, the quantity and quality of the data available to construct the model. This chapter focuses on the data requirements of WPPM, and addresses the problems of collecting and maintaining a WPPM data base. A specific example of such a data base is given in the case study in Chapter 6 and Appendix C, whereas this chapter deals with input data requirements in general. Some users and applications of WPPM will not require the full range of data listed here, which is aimed specifically at a strategic sectoral planning application. Depending on the application, users may wish to delete or change some of these requirements. However, the data needs of all users (down to single mills) will be a subset of those presented here. Because of the multi-period nature of the model, some consideration will also be given here to procedures for recognising and handling risk and uncertainty in forecasted data.

4.1 Classification of Data Requirements

Bremner (1983) suggested several types of data important to forest sector strategic planning. His emphasis was on planning for a single firm, but the same types of data, with slight modifications, are required at the sectoral level. They are:

(i) current and projected type, quantity, quality and ownership of timber supplies;

(ii) current and projected timber prices by quality and ownership, to domestic and export customers;

(iii) current and projected log recovery, product yield, production rates, capacity and cost data for all processing facilities;

(iv) current and projected long term demand and prices for wood products;

(v) order of magnitude costs of capital investments in mills and other operating equipment;

(vi) data on foreign and domestic markets, distribution channels, product acceptance and consumer trends; and

(vii) forecasts of pertinent economic indicators (interest, exchange and inflation rates) and forest policy/management trends.

Whyte and Baird (1983) listed several important aspects for modelling the New Zealand forest sector. Their list incorporates most of the above items, with the following additional data requirements:

(i) environmental and social constraints;

(ii) infrastructural constraints and capacities (e.g. port facilities, transport networks, *et cetera*); and

(iii) data on important inter-sectoral linkages.

The forest sector strategic planning process requires each of these inputs in the most accurate and timely form possible if it is to generate meaningful strategic policies or alternatives. Thus, any forest sector model should incorporate and utilise such data in its framework, allowing for frequent modification and updating.

The data required by WPPM are a subset of the above items. Because of its emphasis on the processing component of the forest sector, some of the factors listed by Baird and Whyte for models of entire forest sectors may be irrelevant. WPPM's requirements can be conveniently classified into three categories, which incorporate many of the elements listed above. These are:

(i) resource data

(ii) processing data (including investment, infrastructure and environment data)

(iii) market and financial data (including interest and exchange rate data)

The range of data required for each period under each heading is summarised in Figure 4-1. Obtaining meaningful data in each of these categories is essential if the full potential of the system is to be realised. The following description, by category, should be considered as a guideline for the minimum requirements for the formulation of WPPM described here. Modified, customised or updated models (especially those incorporating new constraints) may well require additional data (see Chapter 7).

4.1.1 Resource data

WPPM requires data on the supply and per unit cost of four distinct log types for each period in the planning horizon. Supplies should be further broken down by forest and/or import regions. Costs should reflect the amount paid by each mill type considered for each log type from each supply region, including transport costs. The four log types are based on the log grades developed by the Conversion Planning Project Team (Whiteside and Manley, 1987) as outlined in Chapter 2. The aggregate types used by WPPM, along with the corresponding CPPT grade, are presented in Table 4-1.

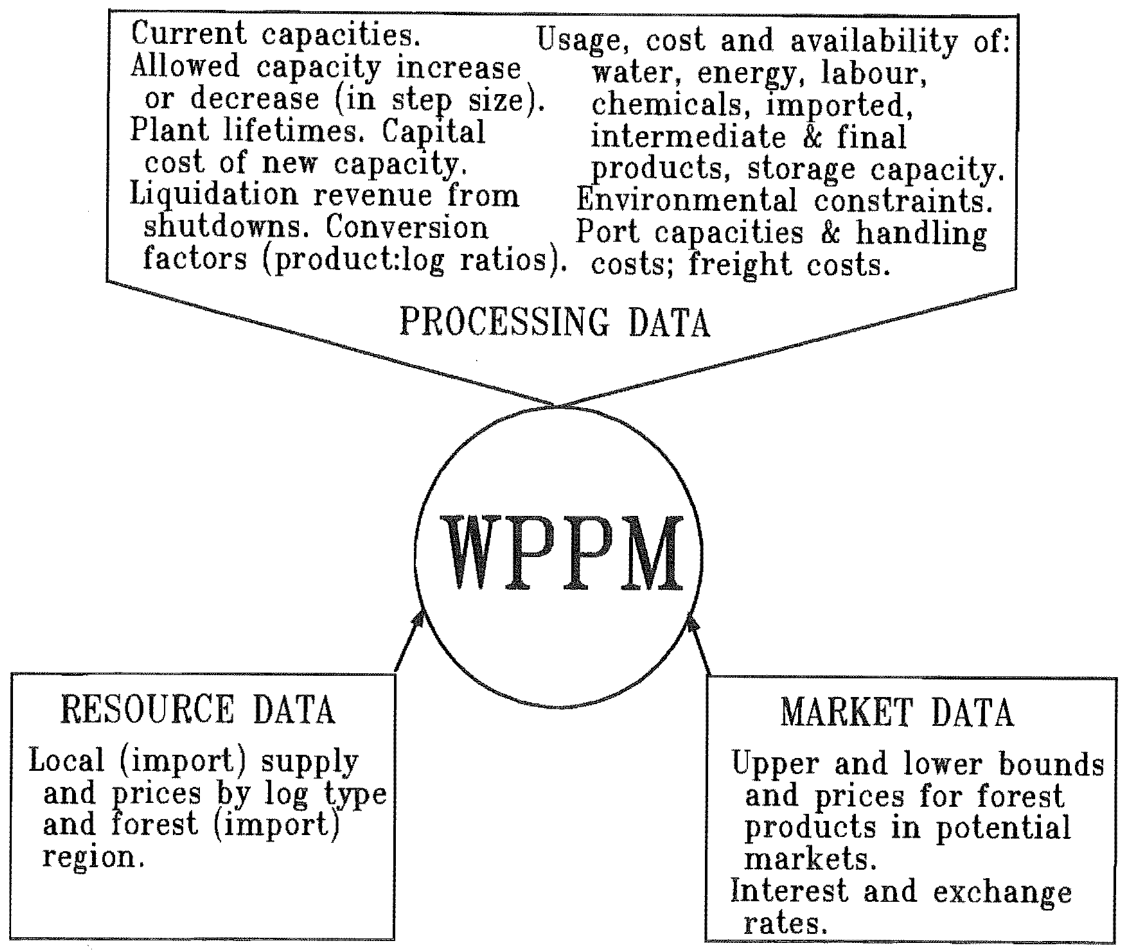

Figure 4-1. WPPM data requirements.

Table 4-1. Aggregate WPPM log types.

Log type	Description[1]	Aggregated grades
1. PL	Pruned logs; sed > 250 mm	P1, P2
2. LUL	Large, unpruned logs; branches < 14 cm; sed > 250 mm	S1, S2, L1, L2, I
3. OL	Pruned or unpruned small logs; unpruned branches < 14 cm; 150 mm < sed < 250 mm	S3, L3 S4, L4
4. RL	Residual logs (sed < 150 mm; unrestricted branch size and sweep) and thinnings	R

Note: 1. The term "sed" refers to log small end diameter.

This reduced set of log types provide a sufficient level of detail for the kind of long term planning for which WPPM is intended. However, it would not be difficult to build more log grades into the model structure, provided that the relevant data were available. Indeed, if the inclusion of a certain log grade is desired despite a lack of hard data, it can be included and the effects of variations in notional supplies and prices examined using sensitivity analyses. This approach could allow the inclusion of, for example, internodal logs in the basic model structure despite a lack of adequate data on supplies and prices of this potentially valuable log grade.

Supply data for the four log types used here can be obtained from the 1986 National Wood Supply Model, revised using the National Exotic Forest Description data base (e.g. as in Burrows *et al.*, 1987a) that was described in Chapter 2. While these figures are easily available, they have to be adjusted (Whyte, *pers. comm.* 1988) as currently they reflect gross rather than realisable volumes. An additional problem with this approach is a lack of resolution. The National Wood Supply Model produces only aggregate totals for each log type in each planning region (e.g. Canterbury). All regional forests are considered in aggregate by this approach. Probably the most reliable regional wood supply data can be obtained by running one of the forest estate models described in Chapter 2 for the specific region under study, including appropriate and more refined growth curves and regional data collected from local forest owners and managers. The NEFD can be used as a starting point for such simulations, and the results can then be checked against official (Ministry of Forestry and Forestry Corporation) statistics. Wood supplies from likely import regions can also be simulated, and upper bounds placed on import quantities of each available log type, based on historical patterns of imports from that region (available in Ministry of Forestry statistics). This approach was taken for the case study model in Chapter 6, with RMS-87 used to generate wood supply schedules for the Canterbury region, by area, ownership and log type. The resulting breakdown of supplies for the four WPPM log grades until the year 2016 are presented in Chapter 6 and Appendices A and C.

Predicting prices for logs (or any commodity) over a 30 year planning horizon is an exercise fraught with uncertainty. A further complication is the interaction between demand for logs (a function of processing capacity and export markets) and their price. Several approaches to this problem have been advocated in the literature, including the spatial equilibrium approach of Pearse *et al.* (1984), Adams and Haynes (1980) and others, the price endogenous approach of Gilless and Buongiorno (1987), the econometric time series forecasting approach of Percy (1985) and others, and the trend analysis/projection approach of the Conversion Planning Project Team (e.g. Horgan, 1987). The methodology employed in the case study lies closest to that used in the last study, although the possibility of incorporating an iterative pricing mechanism within WPPM will be discussed further in Chapter 7.

As stated in Chapter 1, the suggested maximum interval between updating WPPM runs is three years, with an interval of one year (i.e. annual runs) preferable, depending on the application. Price forecasts for logs can then be updated using the latest information available. Since the prices of domestic sawlogs from the country's largest supplier (Forestry Corporation) are determined by a formula based on the consumer price index or CPI (Coffey, 1988), this provides one method of forecasting domestic log prices. The Reserve Bank publishes quarterly predictions of changes in economic indices, including the CPI (e.g. Reserve Bank, 1988) Such forecasts can be used to provide short term (up to two year) predictions of movements in domestic log prices. Unfortunately, with the sale of the Forestry Corporation's assets now an explicit government policy, this method will soon become untenable. Surveys of forest growers and mill owners, always a valuable source of information regarding price trends, may become even more important once the State plantation resource is privatised.

4.1.2 Processing data

The bulk of the data required by WPPM is largely of this category. The model requires the data shown in Figure 4-1 for all existing and potential mill types and processes considered. For existing mill types, there is no practical alternative to surveying mill owners or managers to determine actual production costs and conversions. The logistics of conducting such a survey are briefly discussed in Chapter 6, along with the results of a survey of the existing Canterbury industry. Although mill owners can be reluctant to divulge details of their operations, they can usually be persuaded to provide figures of at least the current order of magnitude. As WPPM requires all costs, revenues and usage of non-wood inputs expressed per unit of production, some manipulation of survey results may be necessary to ensure compatibility.

Availability of non-wood inputs to (and environmental constraints on) production can be obtained from a variety of sources. Capital availability can be derived from discussions with the industry and from the Reserve Bank's liquidity projections. Local catchment authorities can provide figures on water availability and effluent discharge limitations, while energy availability can be provided by local power authorities. Labour availability (and, when desired, lower bounds on the level of employment in the regional wood processing sector) can be obtained from the Departments of Statistics or Labour, through discussions with union representatives and from government policy statements on employment. These agencies can also provide useful checks on the costs of non-wood inputs reported by surveyed processors. The availability of imported products is rather more difficult to quantify, as it depends on production levels in other regions. Historical trends can be used in conjunction with processor surveys to place limits on imports of final products for resale.

Step sizes for increases or decreases in capacity for each mill type should reflect the change in capacity resulting from start-up of one new, or shut-down of one existing mill of that type. The step sizes can be adjusted to model the addition or removal of a single shift, or the re-building or expansion of existing capacity, as well as the introduction and close-down of entire plants. The capital cost coefficients of the associated integer capacity change variables must be modified to reflect any adjustments to step sizes. The liquidation revenue associated with plant shutdowns can be derived from historical figures, when available, or through discussions with processors. For new mills, and particularly for processes not currently existing in a region, it is necessary to turn to literature reviews and/or surveys of plants in other regions to obtain the required technical data. Trade magazines (e.g. *Forest Industries, Plywood and Panel, Tappi Journal*) often contain relatively detailed specifications of new plants/processes, including capital requirements and plant lifetimes. In addition, the CPPT has published specifications for the "greenfield" mills evaluated for that study (Kininmonth, 1987). Although the list of mills is not comprehensive (e.g. there is no costing for an oriented strand board mill such as that which recently started operations in Northland), it can provide a good starting point for new mill data collection.

Projection of processing costs is subject to the same difficulties discussed in the previous section. While most experts agree that long term processing costs are inextricably linked to technological change (e.g. Solow, 1970; Schmookler, 1966), the prediction of such change and innovation is itself a very inexact science. Ince *et al.* (1987) developed a model for predicting technological change in wood processing in the US to be used in conjunction with TAMM (discussed in Chapter 2). However, their model, based on extensive literature review and expert opinion, makes no attempt to assess the uncertainty surrounding their assumptions of technological innovation. The approach recommended here (and applied in the case study) is to obtain the most accurate cost projections possible (through literature review and processor surveys) and to examine the effect of uncertainty in these costs via sensitivity analysis.

Port capacities and costs, as well as any other infrastructural constraints or costs, are the final data items under this category. Port capacity for handling various forest products (or product groups) can be obtained from the relevant harbour boards. Freight and loading costs can also be obtained in this way, and can be checked with local wood products exporters. Although WPPM does not allow for increasing port capacities, solutions which are so constrained will indicate the necessity of port and harbour development if optimal industrial development is to occur. If constraints on domestic infrastructure are included in WPPM, data (e.g. road and rail capacities) can be obtained from sources such as the Ministry of Transport and the Railways Corporation.

4.1.3 Market data

This category of data is both the most important and the most uncertain in WPPM. Since the upper and lower market limits effectively determine which processing options are feasible, it is extremely important that reasonably accurate estimates of these bounds can be forecasted. Techniques for making such forecasts include econometric time series analyses (of marginal utility for new products such as Triboard, discussed in

Chapter 6) and forecasts based on expert opinion, such as the Delphi technique (Fusfeld and Foster, 1971).

Trends in domestic markets can be examined via statistics on housing starts and *per capita* consumption of forest products, as regularly documented by the Ministry of Forestry (e.g. MOF, 1988a, c). These trends can be used to predict future consumption and price levels for various forest products, as illustrated in the studies by Maughan (1986) and the New Zealand Timber Industry Federation (1987). These studies were used to derive domestic demand limits for the WPPM case study. Both, incidentally, reached a conclusion that has been held by many in the New Zealand industry for some time: domestic markets hold little hope for growth.

Export markets, on the other hand, hold the greatest promise for the expansion of New Zealand's wood processing industry, a fact foreseen 70 years ago by Macintosh Ellis. There are many sources of data on export markets and world trade in forest products. The FAO forest trade statistics and demand/supply projections discussed in Chapter 2 are among the best known of these sources. The IIASA data base used in construction of GTM is another source of export market data. Trade statistics and export market reports are available from publications such as *Random Lengths* (e.g. Anon., 1987). Unfortunately, most overseas statistics deal only with an aggregate Oceania, making extraction of data relevant to New Zealand difficult.

Studies of potential export markets for New Zealand's forest products have been carried out at the University of Canterbury and, more recently, at the Forest Research Institute. The former studies, funded by the Forestry Council, examined current markets and future prospects for sawn timber (Coppens, 1981), pulp and paper (Sole, 1981), plywood (Todd, 1982) and roundwood (Smyth, 1984). These studies arose from the 1981 forestry conference, and generally incorporate the assumptions of the working party on industry strategy that reported to this conference. For example, the plywood study was not extended to other board products (e.g. MDF, particleboard) because the working party concluded that export possibilities for reconstituted boards were limited by a small domestic market, but that "plywood looks good" (Working Party on Industry Strategy, 1981). However, since 1981 production of reconstituted panels has almost doubled, with exports increasing by a factor of four, while production and exports of plywood have remained constant (MOF, 1988a). This illustrates some of the pitfalls in attempting to forecast likely markets and processing options.

A more recent study of export prospects for radiata pine products was published by the FRI earlier this year (Whitehouse, 1988). This study included analyses of potential markets for logs, chips, sawn timber, plywood, reconstituted panels, pulp and paper, and minor products. Although the analyses are not without their shortcomings (some of which are discussed in Chapter 6), they are currently the most comprehensive volume and price projections available for forest products exports from New Zealand to the year 2000. These projections (with some substantial modifications) were used as the base for the case study market projections described in Chapter 6.

The economy-wide multi-sectoral models described in Chapter 2 can provide short term (i.e. two to three year) forecasts of trade in selected forest products and export prices. The New Zealand Timber Industry Federation made extensive use of three year projections of exports and prices for logs and sawn timber from the Reserve Bank of New Zealand (RBNZ) model in their recent market report (NZTIF, 1987). Such models do not break down exports by markets, but can provide important price data and calibration for the initial annual periods in WPPM. Likewise the GTM and its associated data base (available at both the School of Forestry and the FRI) described in Chapter 2 can be used to obtain preliminary estimates of future demands and prices for several forest products in selected markets. However this data base is now slightly out-dated; any figures taken from it should be carefully checked with local processors and/or planners to ensure they are reasonable. Note that market demand (and other) forecasts, when they are available at all, will often be quoted in aggregate for the entire New Zealand sector, rather than on a regional basis as required by WPPM. Such aggregate totals must be broken down to amounts applicable to the region under study. The Chapter 6 case study data base (Appendix C) contains several documented examples of such dis-aggregation.

One element remains to be discussed under this category before turning to an examination of methods for recognising and alleviating the uncertainty inherent in a WPPM data set. Although not strictly market data, financial indicators such as interest and exchange rates can be important factors in marketing and processing decisions. The Reserve Bank model provides predictions of interest and exchange rates. These predictions are published quarterly (e.g. Reserve Bank Bulletin, 1988) and are for the upcoming year. Longer term predictions of these quantities are notoriously difficult to obtain, lending weight to the recommendation that WPPM should be updated annually. The interest rate required by WPPM is the real rate, exclusive of inflation. Users should ensure that the rate chosen corresponds to their required rate of return on investment. Exchange rate predictions can be used to modify short term export market demand projections accordingly.

4.2 Risk and Uncertainty in WPPM

The preceding discussion has highlighted many of the sources of uncertainty which will feature in most, if not all, WPPM formulations. Although the prime sources of uncertainty lie in the estimation of market bounds, prices, and costs, other factors contribute to the total uncertainty inherent in the modelling. Timber supplies, prices of inputs to production, conversion factors and usage of non-wood inputs are all subject to variation in the long term and hence contribute to the overall uncertainty associated with the model. Since high levels of uncertainty can negate the strategic utility of the model, it is important that users recognise the sources of uncertainty and are aware of techniques for reducing its impact on strategic decision making. This part briefly outlines methods for coping with uncertainty in WPPM: regular updating and cross-checking of the data base; sensitivity analyses; and other mathematical programming options.

4.2.1 Updating and checking the WPPM data base

Regular updating and cross checking of WPPM data bases is the most effective method of controlling uncertainty in model results. While the other methods discussed in this part can be viewed as "cures" for uncertainty, regular updating can be thought of as "prevention."

Ideally, the model should be used regularly, the maximum interval between updates being three years with one year intervals preferable. As data collection involves a number of different sources and types of information, the process should be standardised. Data collection forms (along the lines of the survey form in Appendix B) should be devised, keeping in mind the need to transfer all data to computer via DATMAT (see Chapter 5). Ideally, the person(s) responsible for collecting and checking data should be reasonably familiar with the model and should have, or be able to gain, access to all relevant data items.

Checking the data base for accuracy is a task that can readily be computerised. The entire WPPM data base could be integrated with existing data base management or management information systems. This type of software can be programmed to check for consistency in the data base, and may even allow for a direct interface with DATMAT, further streamlining the solution process. Such checking, whether computerised or done by hand, should ensure that estimates of the same quantity obtained from different sources are of the same order of magnitude, that there are no unexplained outliers (values falling far beyond their expected range) in the data base and that all costs and revenues are of the appropriate order of magnitude and sign. This process will result in more reliable results from WPPM and will also help to prevent errors such as infeasible or unbounded solutions from occurring later in the solution process.

4.2.2 Sensitivity analyses

The power of post-optimality sensitivity analyses in identifying key variables or constraints in WPPM solutions has been briefly discussed in Chapter 3. Such analyses are relatively inexpensive (in terms of computer time) once an optimal solution has been found, and can be used to isolate variables or right-hand sides (model *parameters*) which significantly influence results. This is done by examining both the range over which each parameter can vary without changing the optimal solution, and its reduced cost or shadow price[1], as reported by the sensitivity analysis summary (see Chapter 5). Parameters with a relatively narrow range and high shadow price have a greater effect on WPPM than those with a relatively broad range and low price. The user can then attempt to gather further information on the isolated parameters (e.g. the price of a given product in a given market), or ensure that the resulting solution is applied with appropriate caution if uncertainty surrounding the parameter(s) cannot be removed (Hillier and Lieberman, 1980). While it is theoretically possible to perform sensitivity analysis on the constraint coefficients as well (Gal, 1979), the process is extremely complicated. Since the constraint coefficients are usually known with more certainty than those of the objective function or right-hand side, and since the SAS/OR software used to solve WPPM does not support this type of sensitivity analysis, it will not be considered here.

Sensitivity analysis of mixed integer programs like WPPM is more complex than the analysis of traditional (non-integer constrained) linear programs. This is because the integer requirement often makes the type of marginal analysis implied by sensitivity analysis irrelevant. For instance, the reduced costs of the capacity change constraints in WPPM are difficult to interpret, as they report the change in the objective function associated with a one unit increase in capacity. While there may be no value associated with increasing the capacity constraint by one unit (i.e. the reduced cost is zero), there is value in increasing it by a larger amount (to allow another capacity introduction). This is a problem that is still unsolved in the field of mathematical programming (Williams, 1978; Murtagh, 1981). The limitation can be alleviated by fixing the integer variables at their optimal values and performing the sensitivity analysis on the continuous part of the problem; this is the approach taken by the SAS/OR software described in Chapter 5. Since the integer variables in WPPM represent major operating decisions (capacity introductions or shut-downs), it seems reasonable to accept these decisions and examine the effects of marginal changes within the basic operating pattern proposed by WPPM.

4.2.3 Other options

Mathematical programming techniques are available which explicitly incorporate a consideration of uncertainty in their solution procedures. These techniques fall under the general heading of stochastic programming (Dempster, 1980). Two of the best known approaches are dynamic programming, and stochastic (or chance constrained) programming.

1. The reduced cost (or shadow price) of a variable is the amount that the objective coefficient of that variable could change without changing the optimal solntion; the reduced cost of a constraint (actually its right-hand side) measures the marginal value of that constraint to the objective function (i.e. the change in the objective function resulting from a one unit change in the availability of or requirement for the item modelled by the constraint).

Dynamic programming was briefly discussed in Chapter 2, where its application to log bucking decision problems was reviewed. The technique can also be used to model uncertainty in multi-period problems. The essential component of a dynamic program is the recursive relationship which describes the next state in terms of current variables. Uncertainty in any of the variables in this relationship can be explicitly modelled by replacing them with random variables (generated from an appropriate probability distribution). While dynamic programming is the most computationally rigorous technique for modelling uncertainty, it is severely limited in terms of problem size. Dempster (1980) reports that most such applications of dynamic programming have been in single product discrete time (less than ten periods) stochastic inventory models. Clearly, unless the problem is very small, dynamic programming will not be a practical approach to modelling uncertainty in WPPM.

Stochastic (chance constrained) programming involves associating random variables with uncertain variables in a linear program; for instance, market demands could be modelled as random variables in WPPM. Forestry applications of the technique have been scarce (e.g. Thompson and Haynes, 1971), largely due to the lack of suitable software for communicating the subjective probability distributions of the random variables to the linear programming procedure. Although the SAS software used to solve WPPM incorporates a range of probability distribution functions, it is currently impossible to access these from within the linear programming solution procedure. If such an interface becomes possible, the incorporation of random variables in WPPM could be considered as a means of explicitly modelling uncertainty.

However, before attempting to employ either of these techniques (or any other algorithm with an explicit treatment of uncertainty), users should undertake a thorough analysis of the deterministic solution. Analysis via stochastic (or, if the model is small enough, dynamic) programming should only be considered if the risk associated with uncertainty outweighs the computational cost of a more rigorous analysis. Often, the type of sensitivity analyses described in section 4.2.2 will provide sufficient detail to allow the causes of uncertainty to be recognised and their effects to be minimised. The next chapter describes in detail how to input data to WPPM, solve the model, and obtain solution reports (including such sensitivity analyses).

CHAPTER 5

WPPM PROGRAMS AND DOCUMENTATION

Mathematical modelling usually involves several discrete tasks: model construction, data collection, data entry, model solution, post-optimality analysis and report writing are all equally important if meaningful, comprehensible solutions are to be obtained from the modelling process. Although the actual computer time spent in solving mathematical programming models like WPPM can be significant, by far the majority of the real time is associated with data collection, handling and reporting. While data collection usually requires a fairly large human input, the other tasks can be relegated largely to the computer. Techniques for facilitating and streamlining data collection for WPPM were presented in Chapter 4. This chapter provides an outline of the structure of and interaction between the computerised data handling, solution and reporting components of WPPM, as depicted in Figure 5-1. The documentation of the model components presented here is specific to Digital Equipment Corporation's Vax 6210 computer, its VMS operating system (DEC, 1987), and its implementation of SAS statistical and operations research software (SAS, 1985).

5.1 DATMAT: Interactive Data Handling and Matrix Generation

For all but the smallest of models, manual preparation of data is prohibitively tedious and error prone. Consider the model presented in Chapter 6 - with over 1400 constraints and almost 3300 variables, the potential for error in entering the model coefficients is high, even when most of these coefficients are zero. Fortunately, there is a substantial degree of structure in WPPM models, allowing most of the data entry and matrix construction tasks to be computerised. While several general purpose matrix generation languages exist (e.g. MGRW - IBM, 1972; GAMMA - Sanders and Smith, 1976; MODELER - Burroughs, 1980), all require substantial skills in both mathematical and computer programming to use. In addition, none is capable of generating the type of matrix required by the SAS-OR software utilised in the solution phase here (discussed in more detail in part 5.2). For these reasons, a custom built system was deemed necessary.

DATMAT is a combined data entry/matrix generation program, written in FORTRAN-77, which also allows users to customise the solution process used by WPPM. The program is structured to allow users with little or no computer or mathematical programming expertise to enter data for and solve WPPM problems. The resulting output is in the format expected by SAS. DATMAT consists of four segments - initialisation, data entry, matrix generation, and specification of solution and output options. A listing of DATMAT is contained in Appendix D, along with a computer log of a typical session. This part documents the program which, through its interactive nature, is largely self explanatory.

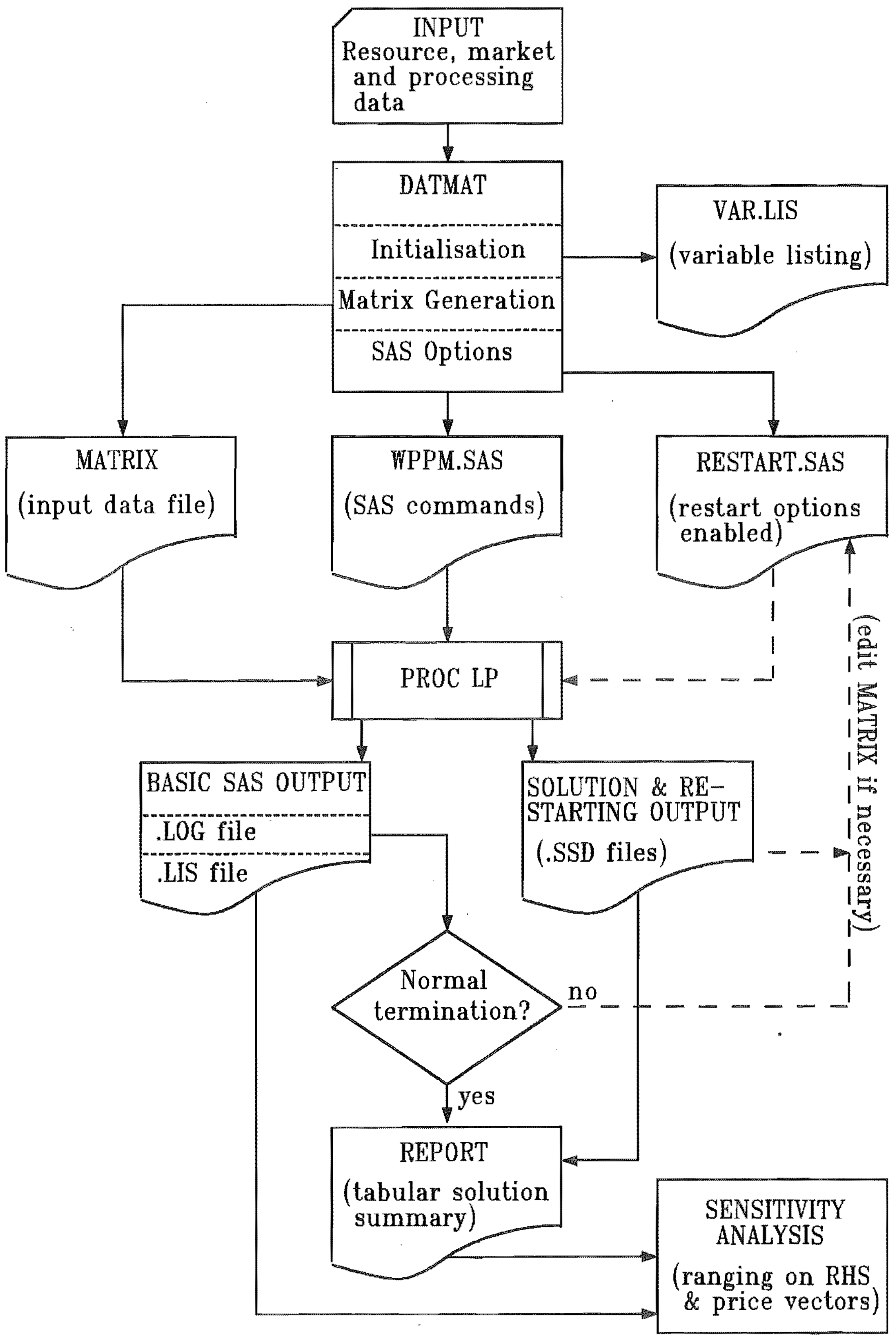

Figure 5-1. The WPPM system.

5.1.1 Initialisation

The program is started simply by typing DATMAT. After displaying a header, the program prompts the user to enter whether data is to be input for a completely new model, or whether a matrix for an existing data file (which may have been edited, for example, using the Vax full screen editor) is to be generated. If the latter option is chosen, the program prompts for the name of the existing data file and invokes the matrix generation phase immediately.

If a new problem is to be entered, DATMAT first prompts for a name to associate with the raw data set. If none is given, the default is DATA.LIS. Next, DATMAT builds a dictionary to define the scope of the problem and to define the levels of the various subscripts and sets presented in Table 3-1. The user is prompted in succession for:

(i) the number of, and labels for, final products (maximum 15)

(ii) the number of, and labels for, intermediate products (maximum 5)

(iii) the number of, and labels for, log grades (maximum 5)

(iv) the number of, and labels for, non-wood inputs to production (maximum 5, including capital)

(v) the number of, and labels for, regional forests (maximum 5)

(vi) the number of, and labels for, import source regions (maximum 3)

(vii) the number of, and labels for, subregions where each product defined as above is (or could be) produced (maximum 5)

(viii) the number of, and labels for, existing and potential plant sizes for each product in each subregion defined as above (maximum 3)

(ix) the number of, and labels for, non-wood source regions (maximum 3)

(x) the number of, and labels for, all domestic markets (maximum 3)

(xi) the number of, and labels for, all export markets (maximum 3)

(xii) the number of time periods and base year for the analysis (maximum 10 periods)

(xiii) the number of non-annual time periods and their length (lengths should be constant at 5 or 10 years for proper discounting)

In addition to the above, DATMAT prompts the user for the number of capacity changes allowed per mill type per period, restrictions on log and product flows, the number and names of objective functions to be generated, the real interest rate to be used in calculating each objective function's coefficients (useful for performing sensitivity analysis on the effect of interest rates), an exchange rate index formula for adjusting export market bounds and the periods it is to apply to, the number of right-hand sides to be included in the problem and the number and name(s) of any additional constraints to be added to the base structure described in Chapter 3. Some of these items have default values, and can be skipped if the default value is acceptable. By default, only one capacity change per mill type per period is allowed; all log types can be transferred to all mills and all products to all markets; there is only one objective function (PROFIT), one right-hand side (_RHS_), and no extra constraints. The default real interest rate is 7 per cent, while the exchange rate formula defaults to a value of 1 (no effect). These default values are generated by leaving the appropriate responses blank. Finally, before exiting from the initialisation phase, DATMAT prints a list of the variables generated in a file called VAR.LIS. The variable names in this list correspond closely to the variables listed in Table 3-1, with some split into two sub-classes for ease of notation. For example, the commodity transfer variable x from Table 3-1 is split into log transfers (X) and product transfers (F). The list is documented, allowing ready recognition of the different variable types. Knowledge of the number and order of variables is essential for entering coefficients for new objective functions and/or constraints. This file can be printed and used as a guide in such operations. The case study VAR.LIS file is listed in Appendix D.

5.1.2 Data entry and matrix generation

Once the initialisation phase is complete, DATMAT constructs a series of tables using the labels defined during initialisation for the row and column headings. These empty tables prompt the user to enter the model coefficients in a succinct and user friendly environment. Each table corresponds to one set of constraints (or objective function) from part 3.3. Leaving any element blank in a table is equivalent to entering a zero coefficient (e.g. if a certain log type is not available from a certain forest, all associated coefficients should be left blank, effectively reducing the number of constraints). Similarly, using the SKIP option for any table results in the skipped constraints not appearing in the model. Care must be taken with this option, however, as the exclusion of some combinations of constraints can lead to unbounded or infeasible solutions (see part 5.2).

Since DATMAT is custom built to generate matrices for WPPM, prior knowledge of the basic problem structure is already represented within the program. For this reason, it is unnecessary to enter coefficients which will always be unity - these are generated directly based on the information provided in the initialisation phase without any direct user input. For example, the coefficients of the variable x will always be unity in the local wood supply constraints (constraints 2.1 in section 3.3.2). Given the number of log types, forests, mill types, periods and restrictions on log flows, DATMAT automatically generates the coefficients for these variables in the appropriate constraints. The tables for these constraints require only the right-hand side value(s) (i.e. upper and lower bounds on the constraint) to be entered. Conversely, the right-hand sides of material balance constraints (e.g. constraints 2.3, 2.5 and 2.11 in section 3.3.2) will always be zero, and only the relevant input-output coefficients are entered in the tables for these constraints. DATMAT performs all discounting calculations on the objective function coefficients and applies the exchange rate formula (if one is specified) to export market bounds in the appropriate periods; only nominal costs, prices and bounds need to be entered for each period.

Each table is preceded by an optional message describing the required input and the expected format. For instance, the conversion (or input-output) coefficients expected for the wood material balance constraints (constraints 2.3, section 3.3.2) are expected to be entered in terms of m^3 product per m^3 log. If any other product unit is specified from the range of options provided by DATMAT (m^2, tonnes, or adt), an automatic conversion to m^3 is performed by the program. This automatic conversion applies to all tables where product units are required.

Incorporating new types of constraint or objective function within the WPPM base model structure is more complicated, and should not be attempted without expert advice. For each new constraint or objective identified in the initialisation phase, the user must enter a descriptive name (see Table 5-1) along with the sets or indices over which the constraint applies (for instance, new constraints on the capacity of road and rail transport of final products to domestic markets would range over the set of all final products, the set of all domestic markets, and the set of all time periods). DATMAT then requires the names of the variables in the constraint, and whether the coefficients of these variables are constant (i.e. unity) or variable. When naming variables, it is sufficient to give the first letter of the variable from the list generated at the end of the initialisation phase. The final step before tables are generated for new constraint(s) is to confirm whether the right-hand side values are constant (and if so, their value) or variable over the range of the constraint (this step is not required if specifying new objectives).

Once all of the data tables have been filled, DATMAT proceeds to the matrix generation phase. This consists essentially of creating a data set acceptable to the SAS LP procedure from the raw data which have been input by the user. The resulting file, MATRIX, consists of one "observation" for each constraint, with each such observation containing a coefficient for every variable in the model (coefficients of zero are represented by a period). Each observation also incorporates an identification variable which names the particular constraint (Table 5-1 contains the names used in the case study in Chapter 6), a right-hand side variable, and a range variable (which allows constraints of the form $a \leq x \leq b$ to be modelled via a single observation). An example of the layout for each observation in MATRIX is given in Appendix D. Although the construction of MATRIX is transparent to the user, a knowledge of the structure of the data set is useful if the problem is to be slightly modified using either the Vax or SAS full screen editors.

Table 5-1. WPPM constraint names.

Name[1]	Description
WLOC	local wood supplies by forest, log type and period
WIMP	wood import supplies by log type and period
WOOD	wood materials balance equations
VEN	intermediate product (veneer to plywood) materials balance
LABOUR	employment level requirements in wood processing
WATER	limits on water availability to wood processing
CAPITAL	limits on capital availability to wood processing
CAPCHG	capacity change equations
MKT	upper and lower bounds on markets
LINK	product sales materials balance
LSTOR	limits on log storage by mill type
FSTOR	limits on final product storage by mill type
ISTOR	limits on intermediate product storage by mill type
PIMP	limits on product imports by mill type
PORT	limits on port capacity by commodity group
Other rows	
PROFIT	objective function
INTEGER	identifies the integer variables (α and β)
UPBDS	identifies upper bounds on integer and other variables
LOBDS	identifies lower bounds on variables

Note: 1. Names must be less than 8 characters long, including up to 3 characters for indexing.

5.1.3 Specifying options

The final step in DATMAT is the specification of solution and output options for the SAS LP procedure (PROC LP). The following discussion outlines the options which can be set from within DATMAT, and gives their default values. Only a brief description of the options and their implications are provided here, as for most applications, the default options will be adequate, and this step can be omitted (using the SKIP option, as above). For large, sophisticated models, however, it may be necessary to adjust the options described here, and to include others described in the documentation for PROC LP (SAS, 1985). Significant gains in terms of run time and tractability can be achieved in such models through a wise choice of options.

Solution options

1. MAXIT1 = *n*
   PROC LP will perform at most *n* phase 1 iterations (iterations leading to a feasible, but not necessarily optimal solution). The default value of *n* is 10 000.

2. MAXIT2 = *n*
   PROC LP will perform at most *n* phase 2 iterations (iterations leading to an optimal solution). The default value of *n* is 10 000.

3. IMAXIT = *n*
   PROC LP will perform at most *n* integer iterations (iterations leading to an integer optimal solution). The default value of *n* is 10 000.

4. TIME=n
PROC LP checks at each iteration to see whether n CPU seconds have elapsed since it began. The default value of n is 18 000.

5. RANGEPRICE/NORANGEPRICE
Instructs PROC LP whether or not to carry out sensitivity analysis on the objective function coefficients. The default is RANGEPRICE.

6. RANGERHS/NORANGERHS
Instructs PROC LP whether or not to carry out sensitivity analysis on the right-hand side values. The default is RANGERHS.

If any of the limits specified in the above options are violated, the procedure prints an error message on the solution log and outputs the current solution. Other options set by default are BLAND (an algorithm to detect and handle cycling - iterating back and forth between the same two solutions- in the LP solution process), DEVEX (a method for reducing the number of variables considered for entering the solution at each iteration) and PRICE=5 (to instruct the DEVEX procedure to consider only the 5 best candidates for entry to the solution). These three options lead to decreased solution times and memory requirements in all but very small problems. All other solution options default to those set in PROC LP. Users are recommended to read the documentation of this procedure for a more comprehensive coverage of all options.

Output options

Output from PROC LP falls into three categories: (i) a solution log which reports any problems encountered during the solution process; (ii) a solution listing which incorporates a problem summary, solution summary, integer iteration log, variable summary, constraint summary, sensitivity analysis summary and, if necessary, an infeasible information summary; and (iii) three permanent SAS data sets containing the currently active nodes in the branch and bound routine for the integer variables (BRANCH.SSD), the current best primal solution (PRIMAL.SSD) and its dual (DUAL.SSD). These three data sets are generated automatically by specifying their names in the ACTIVEOUT, PRIMALOUT and DUALOUT options. PRIMAL and DUAL are used by the report writing program (part 5.3), while BRANCH and PRIMAL can be used to restart the solution process if it is interrupted by the violation of one of the optional iteration or time limits set as above (see part 5.2 for further discussion of re-starting PROC LP). While these three data sets are always created by a WPPM run, the following option gives a user control over the level of output produced by the standard SAS solution listing.

1. PRINT/NOPRINT
Specifying NOPRINT causes PROC LP to omit the variable, right-hand side and sensitivity analysis summaries from the standard solution summary. The default is PRINT; specify NOPRINT when re-running a model or when interested in only the objective function value. Note that most information from the standard solution listing

is summarised and presented in a more easily assimilable format by REPORT, the report writer component of WPPM.

Again, other print control options are available, as explained in the detailed documentation of PROC LP.

Once the solution and output options are entered, DATMAT creates the SAS command files necessary to solve and, if necessary, restart the problem. These files are called WPPM.SAS and RESTART.SAS, respectively. The only difference between the two lies in the use of the ACTIVEIN and PRIMALIN options (rather than a SAS data step) in RESTART, which tell PROC LP the names of the files to use in restarting the solution process. Examples of WPPM.SAS and RESTART.SAS are contained in Appendix D. Once these programs have been generated, DATMAT terminates, returning control to the VMS operating system. Users can then edit these command files to incorporate any PROC LP options that are not available in DATMAT.

5.2 Solving WPPM With PROC LP

To commence the solution process, simply enter SAS WPPM at the VMS dollar sign prompt. This program carries out two functions: it first creates a permanent SAS data set from MATRIX (MATRIX.SSD), the matrix generated by DATMAT, and then uses this data set as input to PROC LP, along with the various options specified as above. The solution process is transparent to the user, using the two phase revised Simplex method and the Bartels-Golub update of the decomposed basis matrix to pivot between feasible solutions (Bartels, 1971). Once an optimal solution to the relaxed (non-integer constrained) problem is found, the solution process changes to the branch and bound algorithm for integer constrained problems (Taha, 1975). Further details on these algorithms and other aspects of the solution process are contained in the documentation for PROC LP. If multiple objective functions and/or right-hand sides are specified, PROC LP solves each in turn, defining a new linear program for each objective/right-hand side combination. Note that up to 10 different objective functions can be specified; there is no limit on right-hand sides.

When the solution process terminates, control is returned to the user via the VMS operating system. At this stage, the solution log file (WPPM.LOG - see Appendix D for an example) should be carefully examined. There are several possible outcomes of the solution procedure; each shall be examined in turn.

1. The solution process may fail to terminate successfully due to iteration or time limits being exceeded. In this case, it is only necessary to restart the process from the unsuccessful termination point, using the PRIMAL and BRANCH data sets to indicate the best solution before termination. Enter SAS RESTART to restart the solution process. Note that the

resulting solution log and listing files are now called RESTART.LOG and RESTART.LIS respectively. This restarting process can be repeated as many times as is necessary.

2. The problem may be infeasible. This usually indicates that two or more constraints are in conflict with each other and that both cannot be satisfied simultaneously. If the solution log indicates an infeasible solution, the solution listing (WPPM.LIS), which contains an infeasible information summary, should be examined. This summary identifies the constraint(s) leading to infeasibility, and the names and values of all variables appearing in such constraints. Once the problem has been identified in this manner, MATRIX can be edited using a full screen editor to change the offending constraint(s) to allow solution. This generally entails only modifying one or more right-hand side values; it is therefore much easier to edit the existing MATRIX file than to create another via DATMAT. Once this has been done, SAS WPPM is specified to solve the modified problem.

3. The problem may be unbounded (i.e. the objective function can increase to infinity). This indicates that one or more constraints have been omitted, or that the bounds on one or more variables have not been imposed. Again, WPPM.LIS should be checked to see if it contains the name of the variable(s) which is unbounded. MATRIX can then be edited as appropriate and the solution process (SAS WPPM) restarted.

4. The optimal solution may be unreasonable (e.g. four MDF mills and two chemical pulp mills scheduled to start production in the same period). WPPM.LIS should be checked for variables with unreasonable values, and examine the constraints in which they occur examined. The units of the coefficients entered for a given constraint should correspond with its right-hand side. If the value of the objective function seems unreasonable, but the variables are reasonable, the cost coefficients in the objective function may need to be checked. The report writer described in part 5.3 can be a valuable aid in detecting and comprehending unreasonable solutions. When the problem is identified, MATRIX can be edited accordingly and the solution process restarted.

5. The optimal solution may be reasonable. At this stage, the report writer program is run to generate a solution summary. Due to the nature of WPPM, there are no "correct" solutions, *per se*; solutions can, however, be checked against historical trends for reasonableness. Verification of WPPM runs is discussed further in Chapter 7.

5.3 Formatting and Reporting WPPM Output

Perhaps the most important component of the WPPM system is REPORT, the SAS program which summarises the solution and post-optimality analyses in tabular format. In large problems, the variable and constraint summaries contained in the standard solution listing (WPPM.LIS or RESTART.LIS - see Appendix D) can be extremely difficult to comprehend, especially for those unfamiliar with mathematical programming. REPORT, as briefly described in Chapter 3, provides a condensed solution summary suitable for presentation or inclusion in more detailed reports for management. Once a reasonable solution is obtained (or if an unreasonable solution requires more detailed checking), SAS REPORT should be entered to generate the solution summary. A listing of REPORT is contained in Appendix D, while examples of its output for the case study in Chapter 6 appear in Appendix A. This part lists the tables produced by REPORT, and describes the supplementary information available via sensitivity analyses from the standard solution listing.

5.3.1 Tabular output from REPORT

REPORT is a program written in the SAS language which extracts and summarises data from the PRIMAL and DUAL output files. The resulting report consists of the optimal objective value together with the following tables in which all values given are annual.

1. Log transfers to each mill type from each forest in each period. One table is generated for each log type, and for total log transfers.
2. Log imports and storage for each mill type in each period, with individual tables for each log type and all log types totalled.
3. Intermediate product flows from source mills to sink mills, by period.
4. Production, imports and storage of all products at each mill type in each period. One table is produced for each mill type, together with a summary table showing totals for all mill types.
5. Sales of all final products from each mill type to each market in each period. As above, one table is produced for each mill type, with a summary table for total product sales from all mill types.
6. Capacity changes (start-ups and/or shut-downs) for each mill type in each period.
7. Utilisation of log supplies by log type, forest and period (one table per log type, showing amounts available, amounts used, and the shadow price, or marginal value to the user, of one extra unit of that log type).
8. Utilisation of available log imports by log type and period, with shadow prices.
9. Employment generation by period, with required levels and shadow prices.
10. Utilisation of available water supplies by period, with shadow prices.
11. Utilisation of available capital supplies by period, with shadow prices.

12. Utilisation of available capacity by mill type and period, with shadow prices.

13. Upper and lower bounds on market requirements, actual sales and shadow prices for each product to each market in each period. One table is generated for each product.

14. Utilisation of available port capacity by commodity and period, with shadow prices.

The data provided in these tables should greatly enhance the strategic planning process, regardless of the level at which WPPM is used. The provision of shadow prices in the final 8 tables gives users a means of deciding the maximum amount (per unit) they could pay to change the various limits and requirements specified in the constraint right-hand sides. There is, however, a limited range over which such changes can be made while still retaining the same optimal solution (i.e. a solution made up of the same variables). The next section shows how to determine these ranges.

5.3.2 The sensitivity analysis summary

If the RANGEPRICE and/or RANGERHS options were set in DATMAT, the solution listing (WPPM.LIS or RESTART.LIS) contains a sensitivity analysis summary. This summary contains the ranges over which the objective function coefficients can vary without changing the optimal solution (RANGEPRICE), together with the corresponding ranges for the right-hand side values (RANGERHS). These ranges also define the limits over which the shadow prices contained in the REPORT output remain valid. The relevance and importance of this type of information was discussed in Chapter 4, and will not be repeated here. The contents of the sensitivity analysis summary include the minimum and maximum changes possible, the variable that would leave (enter for RANGEPRICE) the solution if these limits were exceeded and the optimal objective value at each limit. For right-hand side sensitivity analysis, the summary also includes the values of the variables in the constraint at each limit. For price sensitivity, the summary includes the new price and shadow price of each variable at its upper and lower limits. This information can be used to identify key variables and constraints (those having the most impact on the solution), and can highlight needs for more accurate data, as discussed in Chapter 4. The sample solution listing in Appendix D (RESTART.LIS) contains both price and right-hand side range summaries.

In addition to the full analysis described above, it is possible to perform sensitivity analyses on subsets of the variables or right-hand sides. This involves specifying a new constraint with type PRICESEN or RHSSEN and a coefficient of 1 for each variable to be analysed. It is also possible to use PROC LP to examine changes in the solution as the limits specified in the sensitivity analyses are exceeded; this requires the use of price or right-hand side parametric programming, which can be made available through an option in PROC LP. Users interested in using parametric programming or limited sensitivity analyses with WPPM can be guided by the documentation for PROC LP, which contains full details on the range of sensitivity analysis options available. No further explanation of these options is given here, as the sensitivity analyses available from WPPM should be more than satisfactory for the needs of most potential users.

The documentation provided in this chapter has been necessarily broad, allowing for a wide range of options in the specification and solution of WPPM problems. These include:

(i) the ability to build models of practically any size simply by entering the non-zero coefficients;

(ii) the ability to design customised models, with additional constraints and/or objective functions;

(iii) the ability to customise the solution and reporting processes using various PROC LP options.

The next chapter focusses the concepts presented here, applying WPPM to a large scale regional strategic planning problem.

CHAPTER 6

USING WPPM: A CANTERBURY CASE STUDY

This chapter is intended to serve as a demonstration of how to use the WPPM system, and to show the potential of applying the system to a sector level strategic planning application. While there are many other possible applications of WPPM (e.g. single or integrated mill planning), most would likely be somewhat less complex than that presented here. Thus a wide range of potential users should be able to gain useful insights into the formulation and solution of a relatively large-scale WPPM problem, that resembles their own particular application in some way.

The problem analysed here, to determine the optimal industrial structure for the wood processing sector of an entire region, is of considerable contemporary relevance given the rapidly expanding wood resources in most regions of New Zealand. Results from such an analysis could assist decision makers in industry, who need to assess the viability of potential investments and/or plan the harvesting, marketing or purchase of forest resources, and those in local and national government, who may want to promote rational industrial development, plan the utilisation of forest resources, or assess the viability of competing proposals for processing capacity. Although this chapter serves primarily as an example of the use of WPPM, considerable effort was expended in collecting the data for the case study and ensuring that the model coefficients reflected reality. Attainment of a high degree of accuracy was not always possible, but the resulting data base and model nevertheless represent one of the most thorough analyses of the Canterbury wood processing industry yet undertaken. The results presented here, therefore, could provide a realistic launching pad for further analysis of the region's forestry sector, and beyond.

The first part of this chapter describes the Canterbury region, its forest resources, and the existing wood processing industry. The second part outlines the scope of the model formulated for the case study, and provides a brief documentation of the associated data base (listed in full in Appendix C). The third and final part discusses results from the model solution and shows how sensitivity analysis can be used to assist in the interpretation of these results. Model performance and validation are discussed later in Chapter 7.

6.1 The Canterbury Region

Canterbury, the region chosen for this case study, is bounded to the south by the Rakaia River, to the north by the Conway River, to the west by the main divide and to the east by the Pacific Ocean. This definition corresponds to that used by the NEFDS, which, as stated in Chapter 2, reports resource statistics by county within each region. Figure 6-1 shows the Canterbury region as defined here, together with its constituent counties. It should be noted that the reform of local government currently underway throughout New Zealand will result in the formation of an expanded Canterbury region in late 1989. The new region will incorporate Aorangi region to the south and will consist of nine administrative districts versus the current total of 20 counties (Forrester, 1989). The bulk of the forest resource, existing and potential processing capacity, and domestic market will however remain in the northern part of this new region, currently known as Canterbury.

6.1.1 Forest resources

The Canterbury region has not been well endowed with forests for many years. Early settlers found roughly half of the region under forest cover, most of this in or near the foothills and Banks Peninsula. This was not truly indicative of the timber potential of the area, however, as it is widely held that Maori land clearing and cultivation on the Canterbury Plains caused the destruction of much of this area's primitive forests (Poole and Adams, 1980). The arrival of the first Europeans heralded a new age in forest exploitation, with Canterbury's first sawmills established on Banks Peninsula to provide timber for early settlements. Most of these early sawmills were fairly short-lived, lasting only so long as readily available supplies of wood were at hand. The rapid depletion of Canterbury's indigenous resource, due to the twin pressures of settlement and fire, led to the first early plantings of exotic species. Hanmer State Forest was the first such effort in 1902, closely followed by the Selwyn Plantation Board's first plantings to provide for both shelter and timber needs on the plains.

Indigenous forests, consisting primarily of *Nothofagus* species, still cover 220 000 ha of Canterbury. These forests are concentrated on the foothills and slopes of the Southern Alps and are largely unmerchantable, due to their protection and/or recreational status. With annual production from indigenous forests spiraling ever downward it appears that the bulk of industrial timber produced in Canterbury will continue to come from private and State owned exotic forests.

Canterbury's current area of net productive exotic stocked forest of 49 033 ha (about 4 per cent of the national total) is split 3:2 between the Forestry Corporation and private owners. Major State owned plantations are located at Ashley (9 000 ha), Balmoral (7 000 ha), Eyrewell (6 000 ha) and Hanmer Forest Park (3 800 ha), with smaller exotic plantations at Mt. Thomas, Omihi and Oxford. Documentation of the private resource (approximately 20 000 ha) is less reliable in comparison to that of State owned forests. Private owners include farmers, wood processing companies, informal groups and local authorities: the major forest owners in this category are the soon to be incorporated Selwyn Plantation Board (6 000

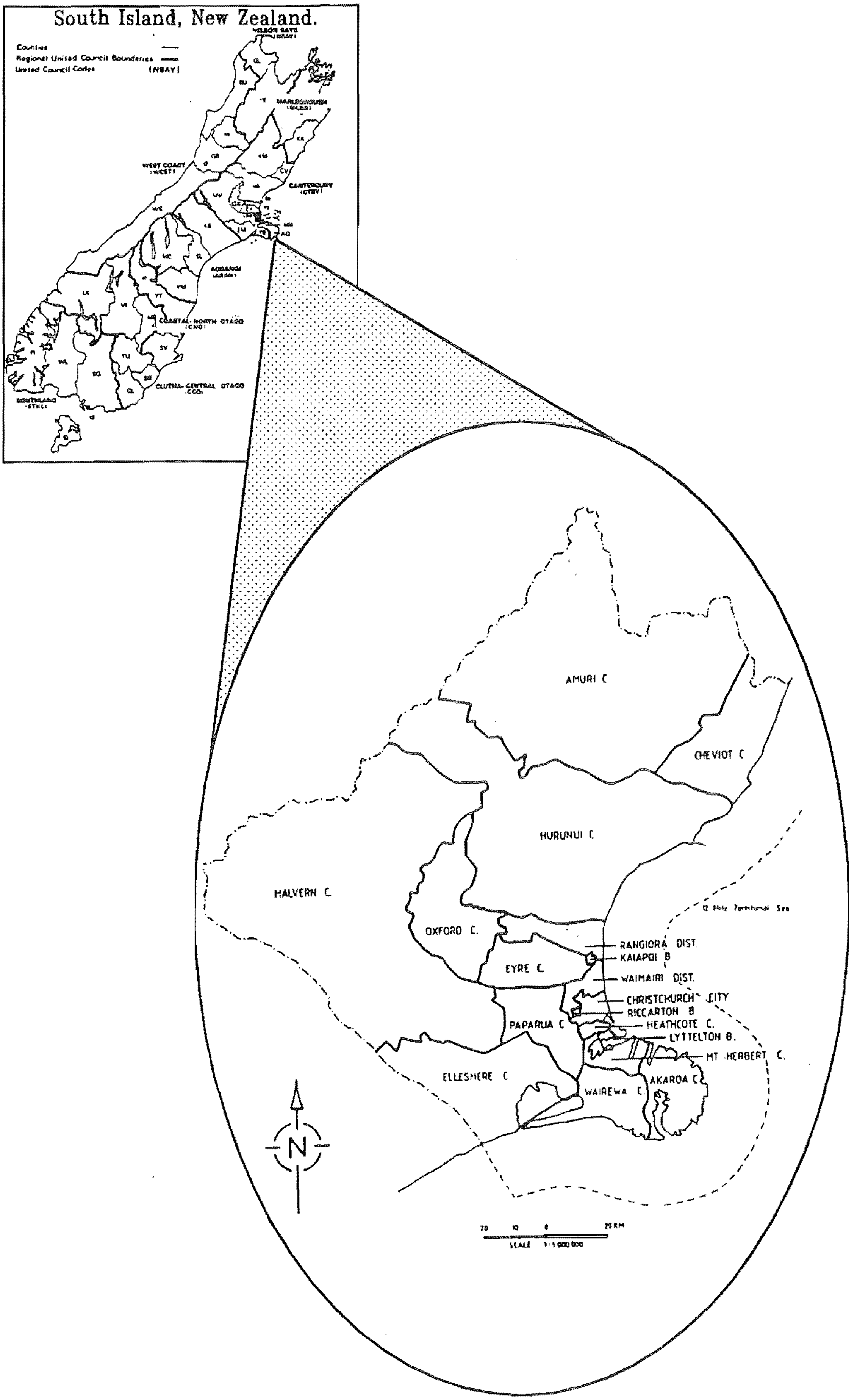

Figure 6-1. The Canterbury region (with county boundaries).

ha), McVicars Timber Group Ltd. (1 200 ha) and Canterbury Timber Products Ltd. (900 ha). The Selwyn Plantation Board, a long standing joint venture between local authorities, has no processing facilities of its own and sells its wood on the open market. The other two major private owners listed are, by contrast, major processors in the region, using the wood from their plantings in their own operations.

Figure 6-2 breaks down the exotic resource by species: 81 per cent of the region's exotic forest area (39 755 ha) is planted in radiata pine, with the remainder consisting of Douglas-fir (8 per cent), other exotic softwoods (10 per cent) and exotic hardwoods (1 per cent). The volume of growing stock in these forests is estimated at 8 089 000 m^3 with a current annual increment of 686 000 m^3 per year (Collins *et al.*, 1988). The current area weighted average age of Canterbury's exotic forests is 14 years, with less than 8 per cent of the exotic forest area holding stands older than 30 years, and almost 50 per cent made up of stands younger than 11 years. While the State dominates in all age classes under 30, private owners hold the bulk of the older resource (Clifton, *pers. comm.* 1987), largely in small farm woodlots and shelterbelts.

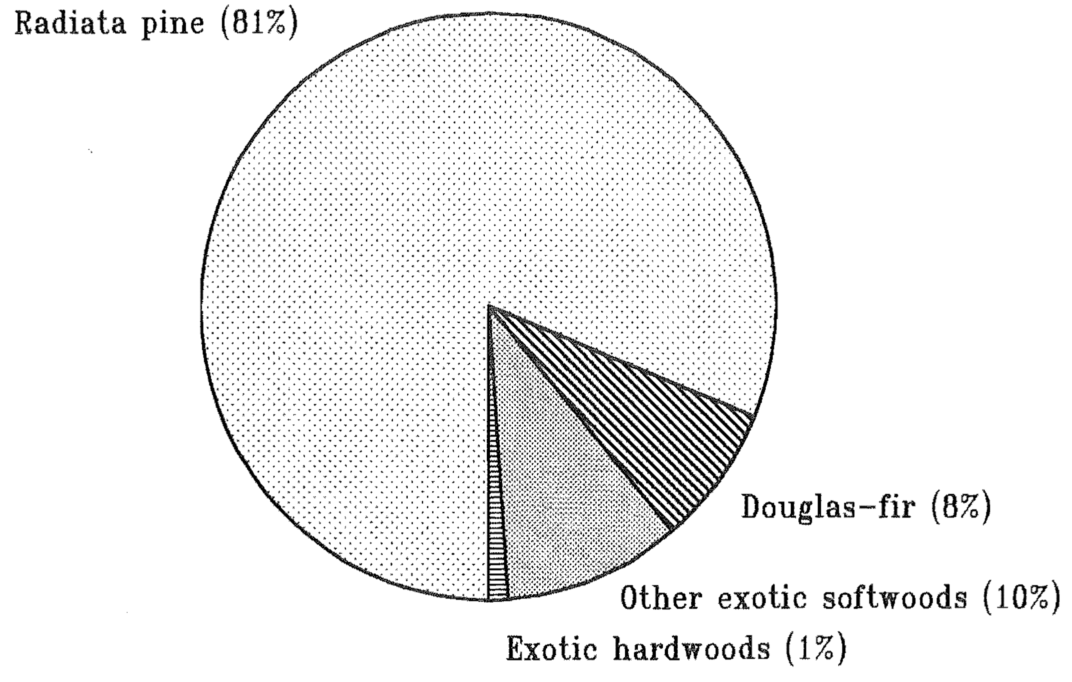

Figure 6-2. Species distribution in Canterbury's exotic forests.

Figure 6-3 illustrates the imbalance in the age class structure of the region's forests. This imbalance has already caused timber shortages which are likely to increase in severity over the next decade. Sawlog prices have risen as farmers and other holders of mature timber realised that demand for their wood exceeded supply. This has resulted in some mills importing logs from other regions (primarily neighbouring Aorangi and Southland), and has contributed (together with sagging markets) to the closure of others. Despite the rather gloomy prospects over the next five years or so, timber supplies will begin to swell dramatically from the mid-1990's on (see Figure 6-4). From 1995, sales from current state forests alone could increase to 100 000 m³/an (NZFS, 1985a). It is this resource expansion which provides the region with the potential to increase its wood processing capacity significantly, and provides the rationale for this case study.

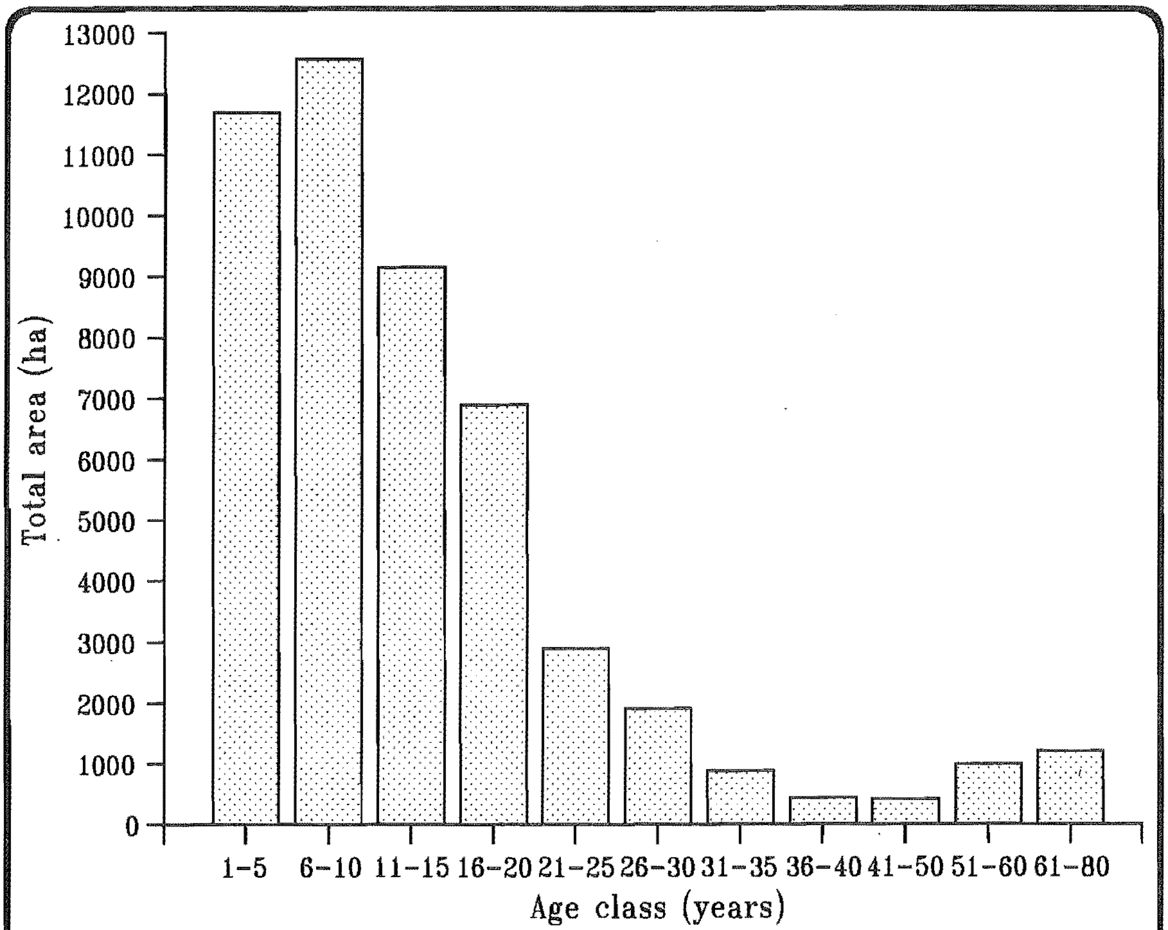

Figure 6-3. Age class distribution in Canterbury's exotic forests.

6.1.2 Wood processing industry

Four major categories of primary wood products are currently manufactured in Canterbury: sawntimber, wood chips, medium density fibreboard (MDF) and veneer. As part of the data collection for this exercise, producers in each category were contacted and surveyed during 1987-88. Manufacturers of each product were located using directories available annually from the New Zealand Timber Industry Federation and New Zealand Forest Industries, from lists of registered saw or chip-mills compiled by the New Zealand Forest Service and published in the New Zealand Gazette (e.g. NZ Gazette, 1987) and, in the case of some of the smaller mills, from a listing of all wood based manufacturers maintained by the local Chamber of Commerce. A brief review of the existing industry, by product, is given in this section. Chip production and usage is incorporated in the discussion of the other products.

Sawntimber. The sawmilling industry in Canterbury, the largest component of the regional primary wood processing sector, was surveyed extensively in 1987 as part of this study. Individual mills were located as described above and sent a form by mail requesting data on production, sales and future plans. Each mill was visited between one and three months following mailing of the survey. The level of cooperation in providing data varied markedly, necessitating several follow-up visits and/or phone calls in some cases. The report arising from this survey (Johnson, 1987a) contains detailed statistics on the industry that were unavailable from other sources (e.g. Department of Statistics). A telephone revision of the survey at the end of 1988 showed relatively few changes. This section summarises the results of this survey and notes relevant changes to 1988; the actual report is contained in Appendix B, along with the survey form which was used to collect the data.

Canterbury's sawmill industry consisted of 21 firms in 1987, seven fewer than in 1984 (see Table 6-1). Eleven of these mills are located within 30 km of Christchurch, producing over 70 per cent of the region's sawntimber. In 1988, the same structure still prevailed, although two mills were on the verge of reducing production or shutting down (Hawkins, *pers. comm.* 1988b). Output varied from 500 - 24 000 m³/an of timber, with the two largest mills accounting for roughly one-third of lumber production. The smaller mills, despite their relatively minor contribution to total output, are important in local economies. Many are in rural locations, providing an important source of income for owners and employees, while utilising isolated tracts of timber to provide timber to rural economies.

Table 6-1. Number of sawmills operating in Canterbury.

Year	1982	1984	1987
Number	34	28	21

Sources: Department of Statistics, 1982 and 1984; Johnson, 1987a (includes one mill selling but not producing).

Total sawntimber production in the region to the end of 1986 was 102 041 m^3, with the industry operating on average at 82 per cent of engineered capacity. 23 400 m^3 of firewood and 41 979 m^3 of wood chips were produced from sawmill residues. Production dropped to about 95 000 m^3 in the year to March 1988, while chip production increased to some 55 000 m^3 at the expense of firewood (10 000 m^3).

In 1986, sawntimber production consumed 209 066 m^3 of logs, with conversion factors ranging from 0.40 - 0.52 (mean = 0.47). The importance of conversion factor, defined as sawntimber volume output divided by log volume input, in mill efficiency is described more completely in Appendix B. In general, conversion factors fell with decreasing mill size, reflecting the lower level of sophistication of smaller mills. Most small mills incorporate circular break down saws, with one or at most two secondary break down saws (usually a breast bench saw). The larger mills are predominantly band mills (single or double), with multiple secondary break down stations (band resaw, gang edger, *et cetera*) for adding value and increasing recovery. It should be noted that none of the sawmills in Canterbury could be classified as state of the art. No mills have installed any of the scanning, positioning or computerised sawing technology that is revolutionising the sawmilling industry elsewhere.

The average replacement value for Canterbury mills is $2,263,095, while the book value is $549,965. The relatively low average replacement value reflects the outmoded and obsolete equipment used at many mills (although the replacement value for the largest mill approached $10 million). Several mills had completely written off their plant and machinery assets; thus the large discrepancy between average book and replacement values. Gross sales of all forest products amounted to $34,569,000. Wood expenses were 24 to 58 per cent (average 30 per cent) of gross sales and 29 to 69 per cent (average 40 per cent) of total manufacturing costs. Labour, the next largest expense, averaged 25 per cent of manufacturing costs, with 349.5 man years of employment generated. All mills operated on a single shift basis, with many cutting back to a 4 (or fewer) day week. Revenues and expenses for four mill size classes are listed in Appendix B. The sawmill types used in this case study are a subset of the classes analysed in the survey.

Framing grades make up by far the major lumber category, amounting to 61 percent of sawn timber production, while clear grades contributed only 6 per cent of the total. Radiata pine constituted 80 percent of sawn timber production, a proportion that will increase as other species (planted primarily in the first planting boom) are cut over and replaced with pine.

The Canterbury sawmill industry exported 21 per cent of its production in 1986, all to Australia through the port of Lyttleton. The remaining 79 per cent was consumed within the region, mainly Christchurch. Exports of sawntimber contributed $7,811,000 in external income to the Canterbury economy. Most of these exports were from the larger mills, four of which have established sales offices across the Tasman. All exporting mills hope to increase sales to Australia within the next ten years, but also realise the importance of finding and penetrating new export markets.

This brief review indicates the current status of the Canterbury sawmilling industry. It is, by and large, inefficient, using labour intensive plant and equipment that is often obsolete. Such mills have survived until recently in the relatively protected domestic market, but will have difficulty adapting to the increasingly international perspective being forced on all New Zealand wood processors. As efficient mills cut costs to compete internationally, they will be able to command an increasing segment of the domestic market as well. Many sawmills now existing in Canterbury may find themselves squeezed out of business in the process.

Medium density fibreboard. The region's sole producer of MDF is located at Sefton, 40 km north of Christchurch. This plant produces 90 000 m^3 of board products annually, operating at full capacity (based on a 4 shift, 7 day week). The plant requires 2.5 tonnes of logs per tonne of product, resulting in a conversion factor of 0.52[1]. The bulk of the raw material used is radiata pine. Chips from the region's sawmills provide 30-40 per cent of the plant's wood requirements, with the remainder supplied in log form. Logs over 40 cm in diameter are sent to local sawmills for debarking and quartering, or to a small private chip mill nearby. The log supply comprises residual logs (small and/or malformed logs together with thinnings) from State and private forests, as well as the company's own small forest holdings. A ten year contract with the Forestry Corporation for the provision of some 70 000 m3/an of residual logs is due to expire in 1990. The company, a subsidiary of Carter Holt Harvey, may well attempt to ensure future wood supplies by bidding on local state forests as they become available for sale.

The production process incorporates a chip digester, a fibre drier, a forming line, an oil heated hot press capable of curing ten boards at a time, and curing and sanding stations. It uses 60 000 m^3 of water (60 million litres), 4.5 million litres of fuel oil, and 120 man years of labour annually, as well as one-eighth of the output of the North Canterbury Power Board (about 5 megawatts of electrical power - Khan, *pers. comm.* 1988). A recent addition is a $6 million energy centre for converting wood waste to power, the result of escalating fuel oil costs and rapidly growing stockpiles of wood waste (some 30 000 m^3/an). This centre will generate 10 megawatts of electrical power, enough to cope with any likely expansion in output. The replacement value of the plant (without considering the energy centre) is $55 million.

The plant can store logs in their log yard, chips in a covered silo or on an open slab, and finished boards in a warehouse. Approximately 70 per cent of production is exported, primarily to Australia and Pacific Rim countries such as Korea, Taiwan and Japan. Prices are best in the domestic market and Australia, with the Pacific Rim countries classed as volume markets, capable of absorbing large quantities of product but at low prices. It will be these markets, however, which absorb the bulk of any future increases in production (Burrow, *pers. comm.* 1988).

Veneer. The region's sole producer of radiata pine veneer is located in Christchurch, and is also a subsidiary of Carter Holt Harvey. The company produces sliced decorative veneers from pine (75 per cent), rimu (15 per cent) and imported logs (10 per cent). Monthly production of pine veneer is 150 000 m^2 (1800 m^3/an based on a veneer thickness of 0.6mm),

1. Panel density = 725 kg/cu. m. Thus, we have 1.38 cu. m/t product. For radiata logs, 1 tonne = 1 cu. m. Therefore, the wood:product conversion is 2.5 ÷ 1.38 = 1.81 cu. m log/cu. m product. Given a loss of 14 per cent in panel volume to wastage, sanding and trimming, this increases to 1.81 ÷ 0.86 = 2.105 cu. m log/cu. m product. Furthermore, since resin (8 per cent) and wax (0.8 - 1 per cent) make up 9 per cent of the panel, the actual wood usage is 2.105 × 0.91 = 1.915 cu. m log/cu. m product. Inverting, the conversion factor of 0.52 cu. m product/cu. m log is obtained.

from a total plant capacity of roughly 200 000 m^2/month. Two grades of pine veneer are produced (clear and knotty), with conversion varying depending on log type. Conversion factors for this and all other processes modelled are tabulated in Appendix C.

The plant comprises a log yard, a sawing station for quartering or halving large logs, a tank for boiling logs, the veneer slicer, drying, clipping, edge gluing and patching facilities, as well as a storage area for finished veneer. The production process uses little water, recycling that used for boiling the logs. It generates 30 man-years of employment annually (based on a single shift, 5 day week), and uses $8,000 worth of electrical power per month (Parish, *pers. comm.* 1988). The replacement value of the plant is estimated to be $5 million.

Up to 60 per cent of the finished veneer is sold locally, primarily to furniture manufacturers who pay up to $2/$m^2$ for clear pine veneer and half that for knotty. The remainder is exported to Australia and the Pacific Rim, often at break-even prices.

This summary of the current Canterbury forest resource and wood processing sector, although brief, indicates the kinds of information which are available, as well as some of the many forms in which they may be provided. The next part of this chapter illustrates the process of creating a WPPM data set from such raw data, and documents many of the key assumptions made in the Canterbury case study.

6.2 The Canterbury WPPM

The flowchart in Figure 6-4 illustrates the flow of materials modelled in each time period and provides a graphic depiction of the scope of this case study. The discussion that follows describes the assumptions implicit in this chart and in the associated data base.

6.2.1 Model scope and assumptions

The first decision to be made in any modelling exercise is that of scope. As Murtagh (1981) states:

> The boundaries of the problem should be as wide as possible. Otherwise, the model may be performing sub-optimization and not grasping the real issues involved. The danger is that one section may be optimized at the expense of others... [also] the model should be as simple as possible. It must be validated, checked and understood, and the issues addressed must be transparent to both the modeler and the manager.

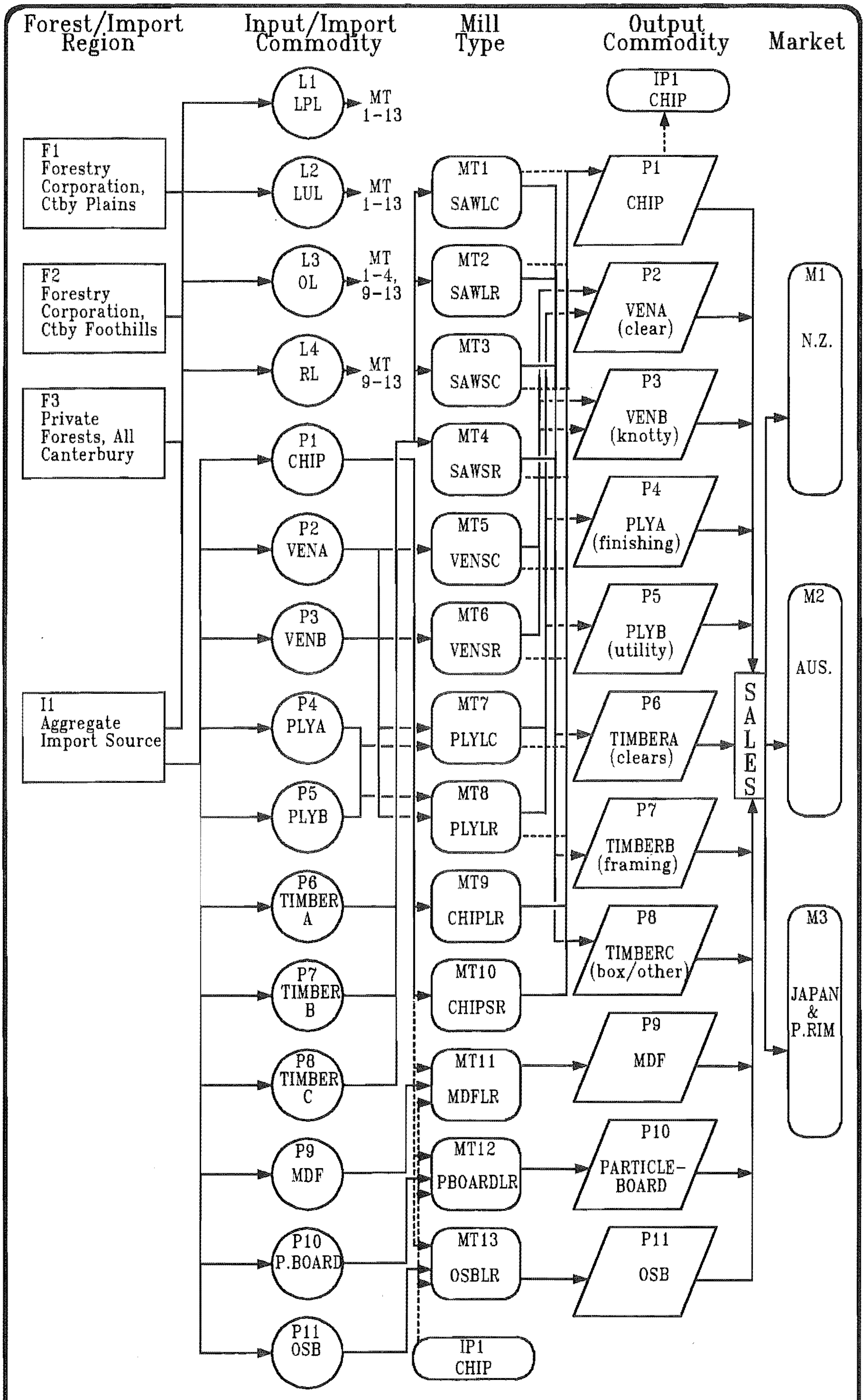

Figure 6-4. Canterbury WPPM flowchart.

Note: Dashed lines indicate intermediate product (chip) flows; all commodity and mill type codes are defined in text.

The Canterbury WPPM was developed with this advice in mind. Table 6-2 outlines the scope of the model in terms of the sets described in Chapter 3. The choice of products and mill types was dictated by the structure of the current industry (as described above), together with reasonable prospects for the future. For instance, the increasing prevalence of large pruned logs in the region's log supply warrants the consideration of plywood plants, although none currently exists in the region. Likewise, increased forest areas will result in more residual logs being available to reconstituted wood processors; hence the inclusion of particleboard and oriented strand board plants as possible processing alternatives. The latter was chosen as an example of a product which is still in the early stages of its life cycle, especially in New Zealand. The country's sole producer of OSB commenced operations in 1987 and is already considering expansion options (Hunt, 1988). The main product sold by this mill is a composite board consisting of an OSB core sandwiched between two MDF panels. Boards can be produced up to 100 mm thick (most MDF panels are less than 30 mm thick), and are being promoted as an alternative to concrete in low cost housing construction. The inclusion of new products and emerging technologies is an important concern in WPPM, and will be discussed further in Chapter 7.

As can be seen from Figure 6-4 and Table 6-2, some important forest products have been excluded from consideration in this case study. The reasons for such exclusions are outlined below. It should be noted, however, that a wide range of processes were characterised in the course of this research, including several (e.g. chemical and mechanical pulp, newsprint, hardboard, softboard) not incorporated as options in this case study. Input/output coefficients for the full range of products examined are documented in Appendix C for future modelling efforts.

Table 6-2. Scope of the Canterbury WPPM.

Set	Size	Comment
CF	10	veneer and plywood (2 grades each), timber (3 grades), MDF, particleboard, oriented strand board (OSB - see text)
CI	1	wood chips
CL	4	large pruned logs, large unpruned logs, other sawlogs, residual logs
CO	2	labour, water
F	3	Forestry Corporation plains and foothills, private forests
IS	1	aggregate import source region
MR	2	Christchurch, rural (see text for further explanation)
MS	2	small, large (see text for further explanation)
MT_n	13	sawmills (4 types), veneer and plymills (2 types each), chip mills (2 types), MDF mill, particleboard mill, OSB mill
OS	1	non-wood commodity source (Canterbury)
D	1	domestic market (New Zealand)
E	2	export markets (Australia, Japan/Pacific rim)
T_a	3	annual time periods
T_o	5	non-annual (5 year) time periods

Wood pulp production, the single largest component of the wood processing sector on a national scale, was not included as a processing option in the Canterbury WPPM. Preliminary test runs of the model examined the feasibility of introducing thermo-mechanical and/or kraft pulping to the region, together with the existing sawntimber and MDF production (Johnson, 1987b). The results of these runs showed that neither pulping option was realistic for the Canterbury region, with constraints on capital, wood supply, water and port capacity combining to preclude them.

Another "process" not considered in this case study is log exports. Although some processors may soon own significant forest areas, at present there are none with sufficient resources to consider exporting logs. The exclusion of log exports from explicit consideration reflects this, as well as another more fundamental assumption. The case study assumes that the processing of logs within the region, in so far as this is economically viable (i.e. profitable), is preferable to exporting logs. Logs which are not used in the industrial structure proposed by WPPM are available for export, allowing for an informal analysis of the region's log exporting capability. Such an analysis would be of particular interest to the region's forest owners. When and if Canterbury wood processors become large scale forest owners, log exports could be easily incorporated as a further process, competing with the others for log resources.

An important influence on the size and scope of WPPM is the level of detail used to model mill types. While it is important to ensure that enough types are included to adequately model differences in efficiency, proximities to forests and markets, *et cetera*, care must be taken to prevent the model growing to an unmanageable size. The approach taken here was to incorporate types representing existing plant groupings, while restricting new processes to realistic sizes and locations. Table 6-3 summarises the mill types considered here and notes the characteristics of each.

Table 6-3. Description of mill types.

Product	Capacity/mill (m^3/an)	Location[1]	Code[2]
Sawntimber	20 000	C	SAWLC (MT1)
	40 000	R	SAWLR (MT2)
	5 000	C	SAWSC (MT3)
	5 000	R	SAWSR (MT4)
Veneer	2 000	C	VENSC (MT5)
	2 000	R	VENSR (MT6)
Plywood	50 000	C	PLYLC (MT7)
	50 000	R	PLYLR (MT8)
Chips	100 000	R	CHIPLR (MT9)
	10 000	R	CHIPSR(MT10)
MDF	100 000	R	MDFLR(MT11)
Particleboard	100 000	R	PBDLR (MT12)
OSB	100 000	R	OSBLR (MT13)

Notes: 1. C - within a 30 km radius of Christchurch city centre; R - other rural districts.
2. See Figure 6-4.

Capacity currently exists in mill types 1, 3, 4, 5, 10 and 11. These existing capacities were mentioned briefly in part 6.1, and are tabulated in Appendix C as well as Table 6-4 in part 6.3. Some compromise was necessary in modelling the range of sawmills currently operating; the four size classes and numerous locations described in the report in Appendix B were combined into the four mill types described above. The seven mill types not currently existing (2, 6, 7, 8, 9, 12, 13) incorporate mills large enough to expect economies of scale, with locations depending on the nature of the operation (e.g. large reconstituted board mills would not be located in Christchurch).

The resulting model has 3 260 decision variables and 1 460 constraints. An examination of Table 3-1 and the following sections shows that mill type is the most common index (after time) in all variables and constraints. Doubling the amount of mill types considered increases the number of decision variables by a factor of almost four (11 310) and more than doubles the number of constraints required by WPPM (3 712). Most importantly, the number of integer variables would increase from 208 to 516. Such an increase in problem size would tax the resources of most large computers, and would most likely exceed the capacity of many smaller ones. Thus, it is important to balance scope and detail so that the resulting problem can be solved in practice.

Although eight periods are modelled in the case study, results from the final period are not included in the analysis of part 6.3. Because of the nature of the discount factor (which results in low profit contributions from latter periods), and the finite planning horizon, the model attempts to reduce production unrealistically in the final period to maximise overall profits. Several methods have been proposed to deal with such "end period" phenomena in linear programming models (e.g. Williams, 1978); by far the simplest, when the planning horizon is long enough, is to drop the final period from consideration in the final analysis. This results in an effective planning horizon of 23 years in this case, still sufficient for long range strategic planning.

6.2.2 Model data

This section outlines key assumptions incorporated in the case study data base, by the categories introduced in Chapter 4. A fully documented listing of the data base is contained in Appendix C.

Resource data. As previously stated, domestic wood supply schedules were generated using RMS-87. These schedules are detailed in Appendices A (Tables A-1 and A-7) and C, as well as being summarised by log type in Figure 6-5. Forestry Corporation holdings were split into two strata: plains (Eyrewell and Balmoral State Forests) and foothills (Oxford, Omihi, Mt. Thomas, Ashley and Hanmer State Forests). This grouping stratifies these forests according to growth rates and risk factor, with foothills forests having significantly higher productivity and lower risk of wind blow (e.g. Crozier, 1984; Forestry Advisory Group, 1982). It is also a rough stratification by proximity to Christchurch, with the plains forests generally nearer the city. Private forests were aggregated in RMS-87, due to the lack of yield data which would allow their distinction by crop types. The availability of log imports was estimated from historical records (Clifton, *pers. comm.* 1987), with the primary source regions (Aorangi and Southland) aggregated to give a total availability estimate. This figure was broken down by log type following discussions with local importing mills (see Appendix C).

Log prices (local and imported) used in the initial periods of the model were based on the results of the mill survey carried out in 1987. These results were checked and confirmed using an unpublished listing provided by the NZ Timber Industry Federation. As predictions of future domestic log prices proved impossible to obtain, a real increase of 5 per cent/an was assumed for the final 6 periods. This assumption, admittedly somewhat arbitrary, is conservative with respect to recent trends in log prices (Hawkins, *pers. comm.* 1988b; MOF, 1988a), but becomes less so when the prices are corrected for inflation. However, the change in ownership of state forests expected this year makes direct extrapolation from past price lists unwise. The effects of more pronounced changes in log prices will be examined via sensitivity analyses in part 6.3.

The wood supply schedules have been adjusted to allow a supply of posts and poles to the region over the planning horizon. This amounts to a 15 000 m^3/an reduction in the first four periods, rising to 20 000 m^3/an afterwards. The model could be extended to consider these products explicitly. This was not attempted here for two reasons: the demand for such products is predicted to remain relatively static in the region (Forestry Advisory Group, 1982), while their production is generally carried out by forest owners rather than primary processors as defined in Chapter 1. When and if such primary processors become significant forest owners, these products could be included in model revisions.

Market data. The current real interest rate of 7 per cent was chosen for this case study. This is among the highest in the world (Anon., 1988), and is a major factor working against new investment in the industry. Since the real interest rate is used, the model solution and data base are inflation free (costs referred to as constant in the following sections are constant when adjusted for inflation). The impact of potential changes in interest rates on the case study solution is discussed briefly in Part 6.3.

Three markets are modelled in this case study. The domestic market refers primarily to the South Island, as freight costs to cross Cook Strait are prohibitive (Hawkins, *pers. comm.* 1988b). The export markets are Australia and Japan/Pacific Rim. The former has traditionally been the only export destination for Canterbury forest products, while the latter is becoming increasingly important, particularly with respect to fibreboard exports. Most producers, when surveyed, predicted that any increases in production would most likely be directed toward the Pacific Rim. If other export markets with prices and/or freight costs significantly different from these become potential customers, they can easily be included in model updates.

Projected changes in the New Zealand exchange rate index to 1990 were obtained from the Reserve Bank survey of expectations (1988). The availability of such projections was the primary reason for choosing this index, rather than nominal rates for each country, as the mechanism for incorporating exchange rates in WPPM. These data were used to adjust projected export limits for all products in 1989 as per constraint 2.10 in section 3.3.2. The exchange rate function chosen for this example is simplistic, assuming a proportional relationship between exports and the exchange rate index. Limited time series of exchange rate indices (Reserve Bank, 1988) and national export volumes of the products considered here (MOF, 1988a) were analysed for linear or logarithmic relationships using the general linear model (PROC GLM) in SAS (1985). Export volumes were adjusted for processing capacity to attempt to isolate the exchange rate effect from that of capacity increases. Since no series of industrial capacity is available, number of employees in each industry was used as a crude correction factor (MOF, 1988a). No significant relationships were found, probably due to several discontinuous shifts in export volumes (per employee), seemingly unrelated to exchange rates. Since the development of equations to predict potential exports from exchange rates is beyond the scope of this thesis, and since small changes in exchange rate appear to have an approximately inversely proportional effect on export volumes, the following equation was chosen for demonstration purposes:

$$f(\varphi_t) = 1 - \{(\varphi_t - \varphi_o) \div \varphi_o\} = (2\varphi_o - \varphi_t) \div \varphi_o$$

where φ_o = base period exchange rate index (60.5 for 1988) and φ_t = predicted exchange rate index in period t (predicted to be 59.0 at the end of September quarter, 1989). Thus, in this case, limits are adjusted slightly upwards by 2.5 per cent, directly proportional to the expected drop in the exchange rate index. This adjustment does not imply that additional exports will automatically occur; if such exports are not profitable, they may remain at the lower limit, or anywhere between the two levels. Refinements to the representation of exchange rate effects in WPPM are discussed in Chapter 7.

Other significant assumptions regarding market limits and prices are as follows:

1. Exports to Australia of products from chip or plymills introduced by the model are not allowed since Australia is the world's largest chip exporter (Buddle, 1988) and is soon to become a net exporter of plywood. According to Theron (1988), New Zealand plywood exporters can at best hope to maintain present export levels to

Australia, leaving little room for new players in this market. All other product/market combinations are considered by WPPM.

2. Export market limits and prices were obtained by combining results from the survey of manufacturers (usually available only for the first three annual periods), from Ministry of Forestry statistics (MOF, 1988c) for current export prices, from the FRI study discussed in Chapter 4 (Whitehouse, 1988), and, for sawn timber only, from a NZ Timber Industry Federation market report (NZTIF, 1987). Some figures required modification, particularly the panel products forecasts made by the FRI, many of which had reached export levels forecast for 2000 by 1988. Such forecasts were revised upwards in consultation with local producers. Forecasts for OSB were unavailable from any source other than the North Island manufacturer, although the FRI study includes this product with fibreboard. This is likely to result in an under-estimate of the export potential of this product, as it is stronger, has a wider range of uses and is still in a relatively early stage of its life cycle in the Pacific (Sweeney, *pers. comm.* 1988). The last factor makes the type of time-series analysis used in most of the FRI projections unsuitable, due to the lack of data. Separate forecasts for OSB export market limits from a potential Canterbury mill were therefore derived in consultation with the North Island producer. All export limits and prices are documented in Appendix C.

3. Domestic market limits and prices were obtained by combining results from the survey of manufacturers with those from a study carried out by Massey University (Maughan, 1986). For both domestic and export markets, where growth rates were given as percentages, existing Canterbury limits and prices were adjusted accordingly. Where products are not yet produced in Canterbury, or where market growth is given in absolute terms for New Zealand as a whole, Canterbury was assumed to be able to capture a maximum of 10 per cent of the forecasted growth. Examples of such dis-aggregation of national figures, together with all domestic limits and prices, are documented in Appendix C.

4. Lower limits on all markets are assumed to reflect the minimum level of Canterbury production committed to a given market. For products not yet produced, or not yet sold in a particular market, the lower limit will be zero. Care must be taken in setting lower limits for existing products, as excessively high limits may result in unprofitable plants remaining open, or in an infeasible solution. Upper bounds, conversely, are assumed to represent the maximum potential sales of Canterbury mills to each market. If these values are set too low, potentially profitable enterprises may not be allowed to produce. If upper bounds are not set, there is potential for an unbounded solution. The sensitivity of the optimal solution to changes in these

bounds can be examined using the type of post-optimality analysis shown in part 6.3.

Processing data. Major assumptions in this category are listed below. All processing coefficients are documented fully in Appendix C. Unless otherwise noted, all data were obtained from the survey of manufacturers.

1. All conversion factors are assumed constant throughout the planning horizon. Factors for existing mills were obtained directly (Johnson, 1987a), while those for potential mills reflect the best existing technology. Because conversion factors are incorporated in the left-hand sides of the wood material balance constraints, it is not possible to examine the sensitivity of the model solution to changes in their values without re-solving the problem with different conversion factors (see section 4.2.2). As described in Chapter 4, industry wide improvements in conversion will be related to the development and introduction of new technologies, neither of which is possible to predict with any accuracy. Since large improvements will likely occur in one industry and not in others, and since it is the *relative* difference in conversion and economic efficiency which causes WPPM to favour one mill type over another, it is reasonable to treat conversions as constant in this type of sectoral analysis. Conversion factors can be updated with the rest of the data base, and any information on upcoming improvements incorporated, before the model is re-run.

2. Capital costs of new mills are assumed constant over the planning horizon. Again, it is unlikely that the relative differences in capital cost for different mill types will change significantly. Capital availability, on the other hand, is assumed to triple over the course of the planning horizon. The Development Finance Corporation has recently reported low investor interest in forestry (Bell, 1989), but this is predicted to change as potential investors become aware of the increasing wood supply.

3. The capital required to build a mill must be available when the decision is made to build the mill. The capital cost is then amortised over the mill's lifetime. A one year lag is assumed between the decision to build a mill and the commencement of production.

4. Water and labour are the only two non-wood inputs explicitly constrained. Constraints on energy and pollution were formulated, but were dropped after discussions with Canterbury power and catchment boards revealed no practical limitations on energy usage or effluent disposal for the types of processes being modelled (Khan, *pers. comm.* 1988; Main, *pers. comm.* 1988). Water usage and availability are assumed constant over the planning horizon, while the minimum labour required to be generated by the industry is allowed to fall from 350 man years/an in the first four periods (1988 - 1995) to

300 man years/an in the final four periods (1996 - 2015). This decrease reflects the belief that the industry will become increasingly capital (and less labour) intensive.

5. The transfer of chips to reconstituted board mills from other regional mills involves offsetting revenues (to chip producing mills) and expenses (to the board mills). It is assumed that the board mills will continue to bear the expense of transporting these chips; it is this expense which is entered as the objective function coefficient for regional chip transfers. Chip imports and exports have the market value objective coefficients shown in Appendix C (file OBJECTIV. PRN).

6. All processing costs (labour, energy, other variable and fixed costs) are assumed constant over the planning horizon, and are averaged for all products produced at each mill type to give costs per unit of total output. Few data exist for current processing costs for the range of mill types examined here; estimates of likely future costs are even more scarce. Since processing costs are included as objective coefficients, the model's sensitivity to variation in these costs can be examined. Such an analysis is presented in part 6.3.

7. Income resulting from the sale of plant and equipment from plant shut-downs is assumed to accrue in the period in which the shut-down occurs (the mid-point of non-annual periods, for discounting purposes). WPPM assumes that the oldest capacity in a given location is shut down first, and that the resulting income amounts to 10 per cent of new plant construction costs (see Appendix C). A mechanism for linking shut down income to plant "age" was considered, but proved extremely complicated, requiring additional integer variables to model the resulting step function. If WPPM suggests the closure of a relatively new plant, the objective function value corresponding to such a solution may need to be modified to reflect higher than anticipated proceeds from the shut-down.

8. Port capacity refers to both Lyttleton and Timaru. Capacity limits, transport costs and handling charges were derived for three product groupings (sawntimber, boards and chips) based on discussions with Harbour Board staff (Johnston, *pers. comm.* 1987), the survey of manufacturers (Johnson, 1987a) and data collected for an earlier study (Baird and Whyte, 1987).

The assumptions described in the preceding sections, and all those documented in Appendix C, have been kept as realistic as possible. The nature and scope of these assumptions indicate areas where data are less than perfect, and where additional analyses may be required. The following part summarises the case study solution, and highlights the type of sensitivity analyses possible.

6.3 Solution Summary and Sensitivity Analysis

This part summarises the general optimal solution from runs of the Canterbury WPPM, detailing the major structural changes that are indicated for the region's wood processing sector and graphically highlighting trends in wood consumption, production and sales. The sensitivity of the model solution to selected parameters is also examined in these sections. Because of the size of the problem and the volume of output to be analysed, it is not practical to provide a comprehensive description of all facets of the solution. Accordingly, some aspects of the solution and sensitivity analysis are examined in less detail than others. The complete tabulated output for this example is, however, contained in Appendices A (solution tables) and D (sensitivity analysis summaries).

6.3.1 General overview

The optimal solution generated profits having net present value of $257 million over the 28 year horizon. When the final period is removed from the analysis (a 23 year horizon), the optimal profit drops to $232 million. While the profit level of the industry is of secondary importance to this analysis, it provides a measure of the effects of structural changes suggested by the model, and is the yardstick used by WPPM to measure the "common industrial good" objective defined in part 3.3. Although profit levels are exceedingly difficult to obtain from private companies (and subsidiary public companies in some cases), a current estimate of the annual profit accruing to Canterbury wood processors in aggregate was derived from survey results (Johnson, 1987a) and industry consultation. If this current figure ($7.6 million) is treated as an annual income over a 23 year horizon, its present value would be about $86 million. Thus, the WPPM solution (with present value of $232 million over the 23 year horizon) leads to a 170 per cent improvement over continuation of the *status quo*. Even when the level of uncertainty in the underlying data base is considered, this improvement in profitability is significant.

Since the current industrial structure is likely to change regardless of whether reference to WPPM is made or not, simply due to increasing log supplies, a comparison of profitability in the initial periods when log supplies are relatively constant provides an indication of differences between the WPPM solution and the *status quo*. Such an analysis was carried out with the condensed test version of the model mentioned in part 6.2 (Johnson, 1987b). It showed that implementing the WPPM solution for the 3 year planning period could result in a 30 per cent increase in profits over the period, primarily by shifting some production from smaller to larger sawmills, and by adjusting sales to various markets. Clearly, WPPM is indicating strategies which are capable of significantly boosting aggregate profits in the region's wood processing industry. The following sections analyse the longer term strategy proposed by WPPM in some detail.

6.3.2 Structural changes

Changes in processing capacity suggested in the optimal solution are depicted in Table 6-4. Mill types not listed here remain at zero capacity throughout the planning horizon.

Table 6-4. Annual capacity by mill type (Mm³/an).

Mill type[1]	Existing capacity	Capacity to end of: 1988	1989	1990	1995	2000	2005	2010
SAWLC	40	40	40	40	40	40	40	20
SAWLR	0	0	0	40	40	40	40	60
SAWSC	35	30	30	25	25	25	25	25
SAWSR	45	45	35	30	30	30	30	30
VENSC	2	2	2	2	4	4	4	4
CHIPSR	10	10	10	10	10	10	0	0
MDFLR	90	90	90	90	90	90	180	180
OSBLR	0	0	0	0	100	100	100	100

Note: 1. Refer to Table 6-3 and Figure 6-4 for mill type code definitions.

This development of the region's wood processing capacity results from the introduction of 2 large, rural sawmills (one in 1989 with capacity coming on stream in 1990, the other in the final period of the analysis), a second veneer mill in Christchurch in the 1996-2000 period, a second MDF plant in the 2001-2005 period, and an OSB mill in the 1991-95 period (although production in these board mills does not reach capacity until the following period). Five units of small sawmilling capacity are shut down over the planning horizon: 2 in Christchurch (1988 and 1990) and 3 in rural locations (2 in 1989 and one the following year). Since actual capacities of the region's small sawmills range from less than 1 000 to over 8 000 m³/an, these closures may not translate directly into actual numbers of mills ceasing operations, but provide an indication of the extent of downsizing required in this class. One of the two existing large Christchurch sawmills is also closed in the final period. Finally, the region's small chip mill is closed by WPPM in the 2000-2005 period. These capacity changes are contained in Table A-6, Appendix A.

The model is clearly trying to shift production from inefficient small sawmills to a newer large mill, which it locates close to forest resources in the aggregate rural sub-region, rather than in Christchurch. As many of the small sawmills are only marginally profitable (see Appendix B), this is not unexpected. WPPM attempts to shift as much production as possible in the early periods, so that wood supplies become available for the new mill. The expansion of this mill type by a further 20 000 m³ capacity in the final period (at the expense of one of the existing large Christchurch mills) would best occur as an expansion of the existing capacity in this class. The model was given the choice of increasing existing capacity by 50 per cent versus building "new" mills in the final four periods; it chose the latter option in this case.

Sawntimber production in the region's smaller mills remains substantially below capacity even after the closure of five such mills by 1990, averaging 30 per cent between 1989 and 2000 in small Christchurch mills and 50 per cent over the same period in small rural mills. At the turn of the century, full utilisation of large mill capacity, together with increasing market demands, results in the remaining small mills increasing production to full capacity once again. This reflects the resilience of the small sawmilling industry in Canterbury which has been observed over the past several years, with many stripping production to extremely low levels (in one case ceasing entirely), but maintaining the option to resume full operations in the event of an upturn.

The second veneer plant commences operations in the first period in which surplus peeler (large pruned) logs become available (1996-2000). This introduction is best viewed as an expansion of existing veneer manufacturing capacity, with the rebuild and re-tooling necessary to double production in the existing mill requiring capital outlay of the same order of magnitude as a new 2000 m^3/an mill (Parish, *pers. comm.* 1988). Despite the availability of substantial surpluses of pruned logs in subsequent periods (see section 6.3.3), no plywood plants are introduced in the region. This is primarily a result of limited markets for plywood, as discussed in part 6.2.

The introduction of the OSB plant in the first five year period (1991-95) attempts to utilise the expanding log resource (log types "other" and "residual") as early as possible, with OSB preferred due to its relatively high profit margin. The plant operates at half capacity for the first period (due primarily to log supply restrictions), increases to 95 per cent capacity utilisation in the following period, and to 100 per cent utilisation for the final two periods (see Table A-14, Appendix A). Likewise, the second MDF plant commences production at 25 per cent of capacity, before increasing to 100 per cent capacity utilisation in the final period of the analysis. Low levels of capacity utilisation can be avoided by constraining production to be greater than some percentage of capacity. Plant start-ups are, however, often accompanied by a period of adjustment during which production slowly rises to capacity. The effect on the WPPM solution of postponing plant introductions can be gauged by examining the shadow price of the relevant market sales constraint(s): in the case of the above MDF plant, postponing introduction to the final period would reduce the optimal profit by about $1 million (the product of the relevant shadow prices from Table A-12 and the 20 000 m^3 reduction in MDF production).

WPPM closes the small regional chip plant in the sixth period (2001-2005), as sufficient wood chips are forthcoming from the region's sawmills to supplement the MDF plant's log supply. The chip plant's full capacity was only used once by the model, reflecting the relative inefficiency of producing chips in this manner. It should be noted that although the optimal solution allocates all veneer and sawmill residues to the MDF plant(s) (Table A-3), the variables allowing such transfers to the

OSB mill were classed as "alternative" in the solution summary. This means that alternative solutions exist (having the same objective value) that incorporate chip transfers to the OSB mill. Clearly, these solutions would also involve some juggling of the other sources of wood to these mills to satisfy production requirements. Most large-scale problems such as this will result in some variables being classified as alternative. These should be noted, and the possibility of other equivalent solutions considered when undertaking analysis of WPPM output.

6.3.3 Wood consumption

The availability of local and imported logs throughout the planning horizon is depicted in Figure 6-5, with consumption of each log type in the region plotted in Figure 6-6. Comparison of the two graphs shows that while supplies of sawlogs and lower grades (LUL, OL and RL) are almost completely utilised, the pattern of regional development indicated by WPPM results in substantial surpluses of large pruned logs over and above the regional processing industry's needs. The complete breakdown of log shipments from each forest region to each mill type is contained in Tables A-1 and A-2, while Tables A-7 and A-8 compare consumption and availability of each log grade.

Wood consumption in sawmilling rises from some 215 000 m^3 in 1988 to 280 000 m^3/an in the final period, the bulk of this in large and small sawlogs (LUL and OL), although the smaller mills are forced to purchase more expensive pruned logs in the early periods when log supplies are tight. Veneer manufacturing uses only pruned logs (PL), primarily from Plains forests, with consumption rising from 3741 m^3/an to 5435 m^3/an over the horizon. Consumption by the reconstituted board industries grows from 85 000 m^3 of residuals (RL) in 1988 to just under 400 000 m^3/an (RL and small quantities of OL) in the final period, easily the largest increase. Details of production resulting from these consumption levels are provided in section 6.3.4.

Examination of Table A-7 shows that all local wood supplies (including pruned logs) are completely utilised until the end of the fourth period in 1995, with the exception of about 20 000 m^3 of thinnings (RL) not utilised in 1989. In the fifth period, the supply of sawlogs (LUL and OL) increases to satisfy the needs of most sawmillers, with a corresponding drop in utilisation of the more expensive pruned logs. In the final two periods, pruned logs are sold only to the veneer mill in the limited quantities required to produce its clear veneer (Table A-1).

Wood imports portray a similar trend, with imports of pruned logs falling to zero after the third period (Table A-8). Imports of large unpruned sawlogs cease after the fifth period, while small sawlog (OL) and residual log (RL) imports continue to supplement the region's own supplies throughout the planning horizon. The continuing shortage of small sawlogs

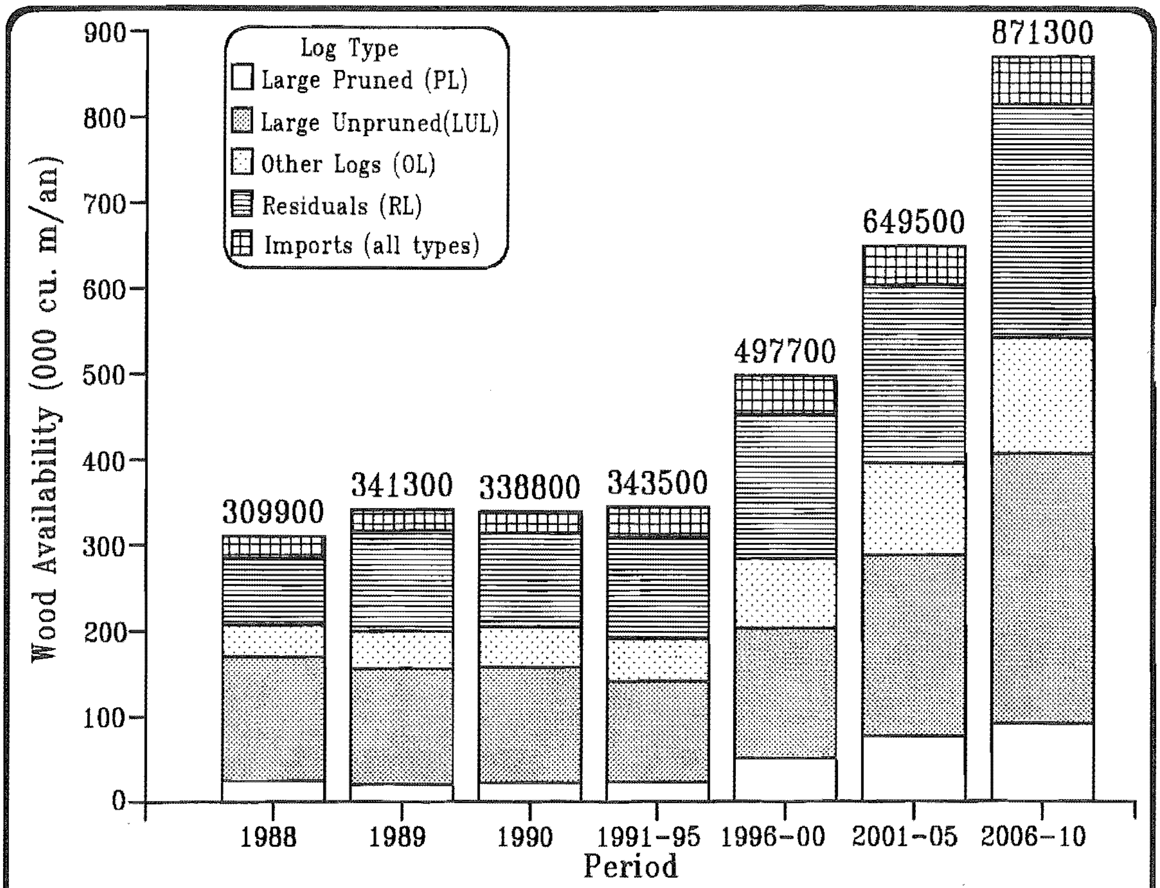

Figure 6-5. Annual wood availability in Canterbury.

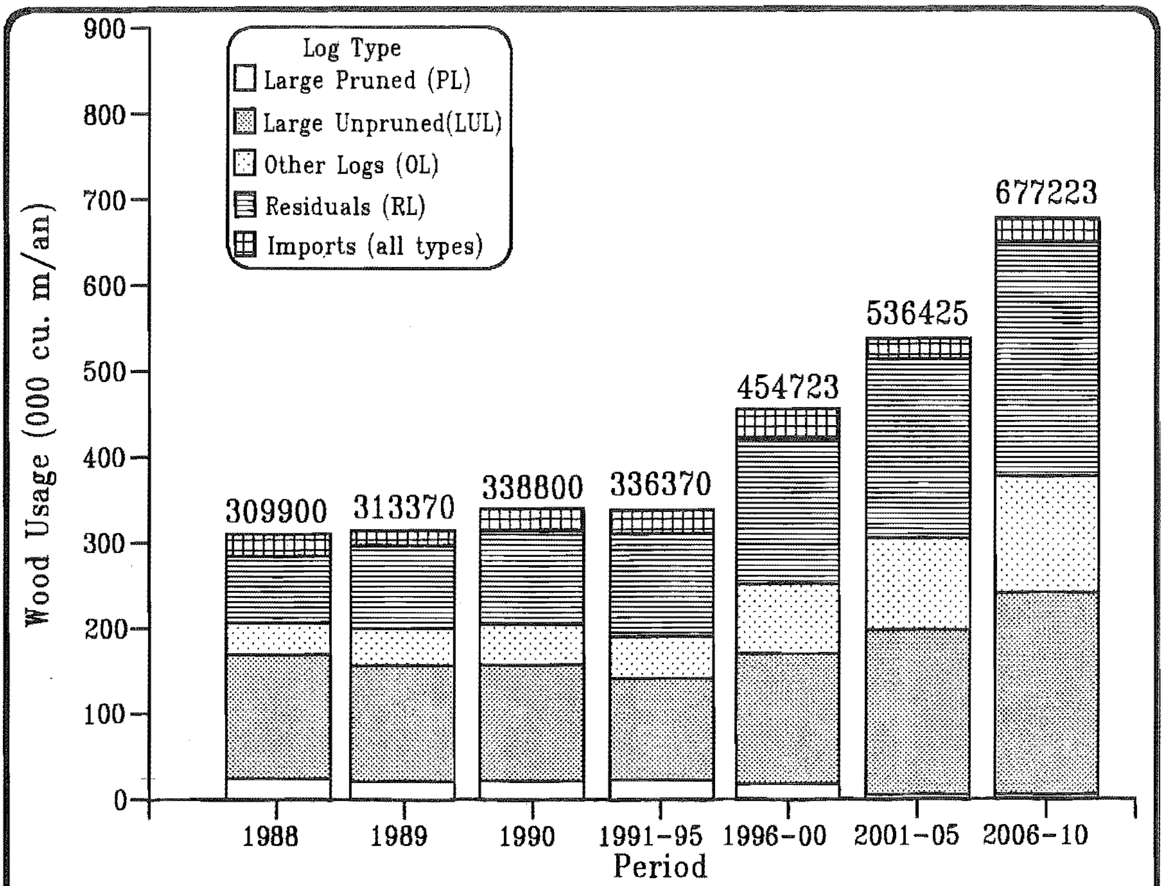

Figure 6-6. Annual wood usage in Canterbury.

is due to the wood demands of the reconstituted board mills, which due to expansion use greater quantities of this grade than the sawmilling industry in the fifth and final periods (Table A-1).

The economic value of wood to the region is reflected in the shadow prices of the various log grades shown in Tables A-7 and A-8. These range from zero (indicating that an extra cubic metre of that log type is worthless to the regional processing industry, there already being a surplus) to $411/m³ for large unpruned sawlogs from State owned plains forests in 1990. This figure represents the marginal profit that would accrue to the region if a further cubic metre of this log type were available to be processed into sawntimber, veneer and chips, then sold in the most profitable market having an unsatisfied upper bound. The right-hand side range analysis in Appendix D shows that this value is valid for availabilities ranging from 9100 to 13 100 m³, with the actual availability of this category of log specified as 12 900 m³ in 1990 (Table A-7). Analysis of Tables A-7 and A-8 in this light shows up the extent of the short-term wood shortages facing the Canterbury industry - shadow prices of all log types other than residuals remain well above $200/m³ for the first three periods, then begin to fall as supply constraints ease. Residual logs, on the other hand, have relatively low shadow prices in the early periods, when there is enough log and chip volume to satisfy the needs of the single MDF plant. The introduction of the OSB mill in the fourth period, however, strains these supplies and is accompanied by an almost eight-fold increase in the shadow prices of residual logs.

A shadow price of zero should not be interpreted as a lack of value. It is only in the model's context that log types with zero shadow prices are deemed worthless. In reality, the surplus of pruned logs indicated in Table A-7 will almost certainly be exported, either to other regions within the country with the processing capacity (e.g. plywood mills) to utilise them profitably, or (most likely) to Pacific rim countries hungry for wood to fuel their own development. Although modelling such log exports is beyond the scope of this case study, the results presented here provide a lower limit on the volumes of such exports possible, given the assumption of local processing having first priority. Such exports become feasible initially in the fifth period (1996 - 2000), with a surplus of 33 000 m³ of pruned logs from current State forests. The exportable surplus more than triples in the following period, to 110 000 m³ (70 per cent pruned, 30 per cent unpruned), then increases to 205 000 m³ in the final period (40 per cent pruned, 60 per cent unpruned). Clearly, there is scope for substantial log exports from Canterbury, in addition to the industrial expansion detailed here.

Analysis of the price range summary contained in RESTART.LIS (Appendix D) shows that the optimal solution reported here is relatively insensitive to changes in log prices (the first 856 'X' variables in the price range summary). Many of these variables allowed infinite ranges for the associated objective function coefficients and were deleted from the output file for brevity. Those with finite ranges show the upper and lower objective coefficients for which the solution structure (i.e. variables in the optimal solution) remains the same, together with the new objective value at these limits. For example, the cost of unpruned sawlogs from private forests to small rural sawmills in 1988 (variable X2341) could decrease from the actual level of $53/m^3 to $42/m^3 or increase to infinity without changing the structure of the optimal solution. The optimal objective value would rise to $257,493,269 in the former case, less than one-tenth of a per cent improvement over the original solution. Examination of the wood supply variables from the latter periods having finite log price ranges leads to the conclusion that wood prices in most cases could increase by up to 20 per cent before the solution (and industrial structure) proposed by WPPM would be altered. This means that real increases in log prices could be substantially greater than the 5 per cent/an assumed, without affecting the optimal industrial structure proposed by the model. When the price range limits are exceeded, however, the entering variable (the new variable that enters the solution as the one whose limit has been exceeded leaves) is unfailingly a capacity addition or shut-down. Intuitively, this reaction is understandable as substantial changes in wood prices will make the difference between profit and loss in many mills. The data in Appendix D show the wood prices associated with such capacity changes, essentially pinpointing the break-even point for potential or existing mills in terms of wood costs.

6.3.4 Production and sales

The expanded wood processing sector in the Canterbury region generates 720 man-years of employment in the final period (2006 -2010), almost double the current level, and well in excess of the lower limit placed on employment. After a slight fall in the initial periods, employment begins rising in the fourth period, increasing steadily until the end of the horizon (Table A-9). Given current employment statistics, no upper bounds were placed on labour supplies. However, it should be noted that most of the capacity increases suggested by WPPM are in rural Canterbury. As unemployment is predicted to worsen in the medium term (e.g. Reserve Bank, 1988), it seems reasonable to assume that labour supplies would relocate or commute to the new mills as required.

Water usage is well within the bounds set for this modelling exercise (Table A-10). Capital expenditure also lies safely within the hypothetical bounds set here. These "bounds" were set so as to allow development to occur, assuming that profitable investments will attract the necessary capital. The required capital outlay for the regional development proposed is $152 million, with most of this ($125 million) required for the reconstituted board expansions starting in the late 1990's (Table A-11). Examination of the right-hand side range analysis for the capital constraints in RESTART.LIS (Appendix D) allows the effects of decreases in capital availability to be assessed. For example, if capital availability falls below the level required for the new reconstituted board mills in periods 4 and 6 (constraints CAPITAL4 and CAPITAL6 respectively), the entering variable is the start-up of a large export chip mill (mill type 9).

As expected, exports of wood products fuel the growth of the region's industry, increasing in importance for all products over the horizon. Existing port capacity will be more than sufficient to handle the increased throughput, however, with no more than 25 per cent of capacity utilised in any period (Table A-13). Port capacities will exceed requirements even if anticipated harbour developments do not materialise. The majority of Canterbury's forest products exports should continue to be exported from Lyttleton, with small amounts (and any log exports) from Timaru. The following sections detail selected production and sales statistics for the major product groups. Since chip production was briefly mentioned in the preceding section, and since all chips produced in the model solution are sold to the MDF mill (Tables A-3, A-12), this product is not analysed further here.

Sawntimber. Figures 6-7 and 6-8 depict the production and sales (by market) of the three sawntimber grades examined here (clears, framing and box grades), aggregated over all mill types. Minor differences between total production and total sales in these graphs are due to product imports and storage, shown in Table A-4. The relevant data for these graphs and all others in the following sections (broken down by mill types) are detailed in Tables A-4, A-5, and A-12.

Surprisingly, production of clear grade sawntimber remains relatively constant in the region over the planning horizon. This is due to the limited market prospects currently perceived for clear radiata timber and the relatively high costs of obtaining it in the largely obsolete Canterbury mills (conversion factors for clearwood are naturally lower than for other grades). Framing timber production, the mainstay of the current industry, rises by 20 per cent, with most of this directed to the domestic market, while box grades increase by 50 per cent, half of this increase going to the Japan/Pacific rim market. The increase in framing timber production is supplemented by a relatively constant import level for this product of about 2500 m^3/an. In total, sawntimber production increases from just under 95 000 m^3/an in the first period to 135 000 m^3/an in the last.

While exports of sawntimber grow slowly over the horizon, domestic sales continue to provide the bulk of the sawmilling industry's income, falling only slightly from 75 per cent of production in the initial period to 70 per cent in the final. Although prices of sawntimber sold on export markets are somewhat higher than domestic levels, high freight costs per unit volume (and the relatively low volume shipments from the various mill types that are involved) work to reduce exports of sawntimber products and favour the more lucrative (but slow growing) domestic market.

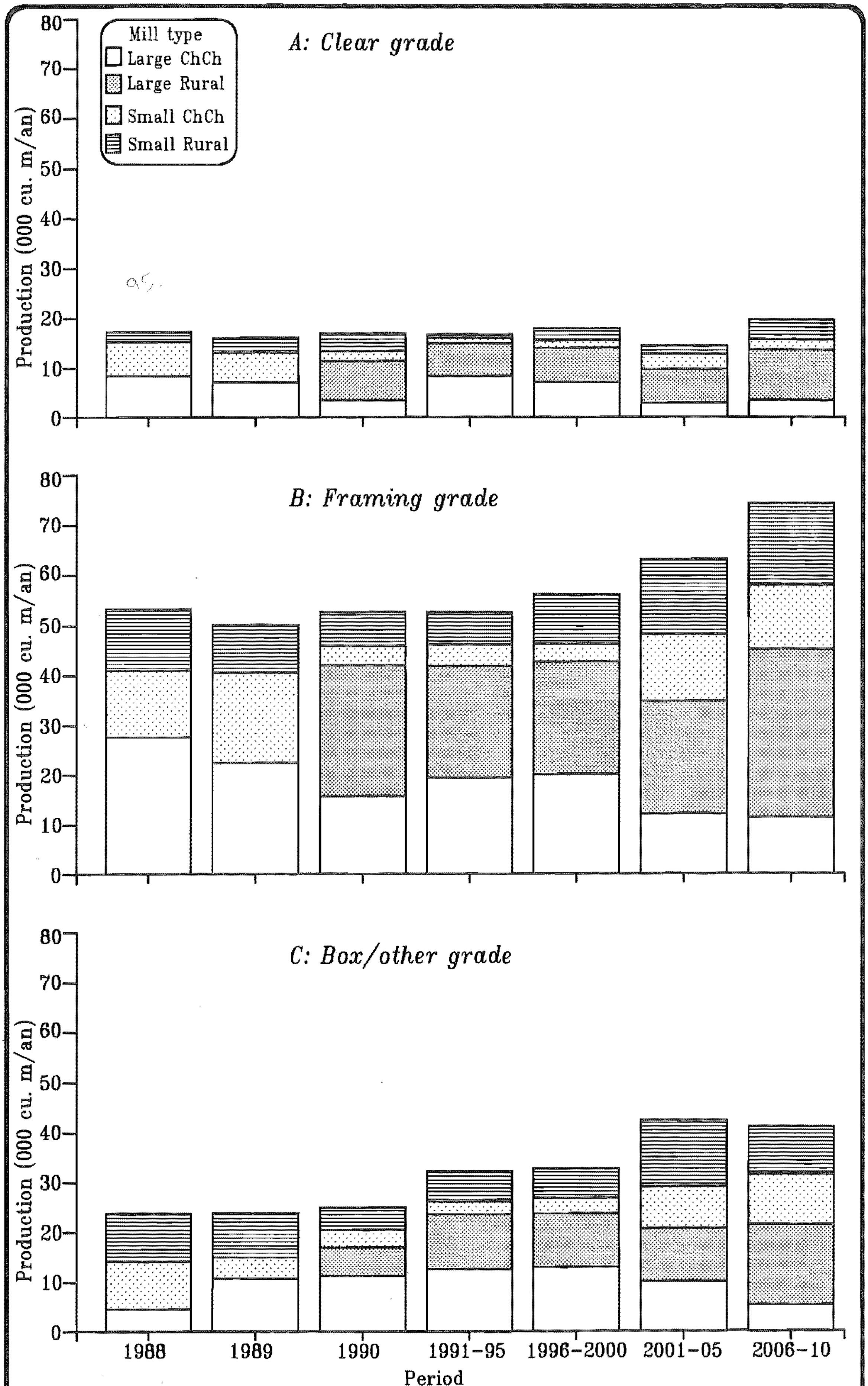

Figure 6-7. Annual production of sawntimber in Canterbury.

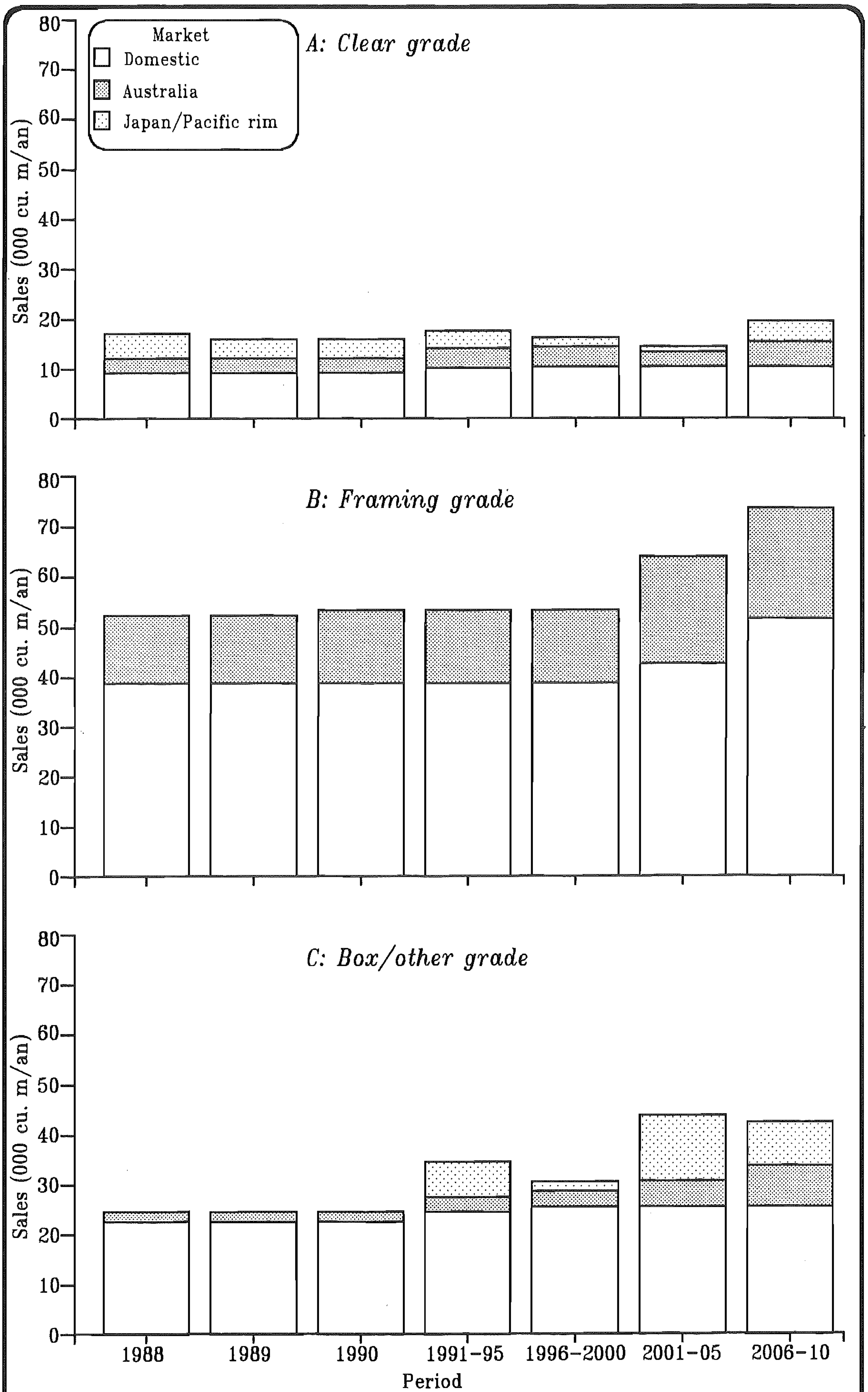

Figure 6–8. Annual sales of sawntimber from Canterbury.

The lack of profitability in much of the sawmilling industry is demonstrated in the low shadow prices for framing and box grade timber in Table A-12. These values, averaging less than \$10/m^3 over the horizon and generally applicable over a fairly wide range of market bounds (Appendix D), imply that the optimal objective value would not change markedly with any increases in market bounds. The smaller mills are primarily responsible for these figures, with their low efficiency and high processing costs offsetting the small profit margin of the larger mills on these commodities. Only clear timber has a relatively high profit margin (shown by the high shadow prices associated with the upper market bounds on the domestic and Australian markets). If greater demands for clear timber in either of these two markets arose, it would be profitable to shift sales to them from the Pacific rim market. Since the penetration of new markets for clear timber (such as the Pacific rim and specifically Japan) will generally require a period of sacrifice while the product establishes itself, careful consideration should be given before transferring sales out of these regions, especially if establishment in new markets is a long term strategic objective.

Sensitivity analysis of production costs shows a similar trend to that presented for wood costs above, although finite ranges for almost every sawntimber production variable are found in Appendix D. These ranges are, however, relatively wide, narrowing somewhat for the smaller mills to indicate the greater sensitivity of these mills to production costs. For example, production costs of clear timber at small Christchurch mills in 1989 (variable P632) can only increase by 15 per cent before the solution structure changes; those in large Christchurch mills could increase by almost ten times before a change in the solution structure occurs. This large increase does not imply that sawntimber produced under such costs would be profitable; rather, it reflects the necessity to produce a certain amount of sawntimber to meet market demands, regardless of cost, and the preference of the model to do so in the larger mills. As with wood costs, the entering variables when production cost ranges are breached are almost always capacity changes, usually in the same mill type.

The wide price ranges associated with clear timber sales variables in Appendix D, when compared with the corresponding ranges for framing and box grades, reflect the relative insensitivity of the solution to these prices. For example, the price of clear timber produced in large Christchurch mills for the domestic market in 1989 (variable F6112) can range between \$308/m^3 and \$2,222/m^3. The corresponding price range for box grade timber from the same mill for the same market in this period (variable F8112) lies between zero and \$158/m^3. Such variations, indicating significant differences in profitability, are found between most of the clear, framing and box grade sales variables. Expanded markets for clear timber can be exploited over a much wider range of prices than those for lower grades, given the industrial structure proposed. It seems clear that in addition to concentrating production in larger, more efficient mills, Canterbury sawmillers should also focus on expanding markets for and production of higher valued products such as clear timber if it hopes to improve its profitability.

Veneer. Figures 6-9 and 6-10 show production and sales for the two veneer grades produced in the Christchurch mill(s). Production of the two grades remains fairly constant over the horizon, jumping by just under 50 per cent with the increase in capacity in period four, but maintaining a ratio of about 1.25 m^3 clear veneer to 1 m^3 knotty throughout. Low levels of imports of clear veneer, ranging from 39 m^3/an to 76 m^3/an, supplement these production levels.

Exports of clear veneer remain constant over the horizon at 600 m^3/an, while the domestic market for this veneer grows by almost 100 per cent to 998 m^3/an in the final period. This increase accompanies the rise in production of reconstituted boards, which uses veneers to laminate (and add value to) board products. Export and domestic sales of knotty veneer are roughly equivalent for the first three periods, after which increased production of this grade from the new capacity is targeted at export markets, primarily the Pacific rim.

Clear veneer sales remain at lower limits for all markets, only increasing to reach upper limits on the domestic market in the final periods. There is only one positive shadow price in Table A-12 for this grade (domestic market in period 4). Knotty veneer, however, lies at or near its upper bounds in most market/period combinations, with corresponding positive (albeit low) shadow prices. This slightly counter-intuitive result occurs because veneer production is a small component of the regional sector, with low profit margins. The market requirements for clear veneer makes the purchase of expensive pruned logs necessary, from which knotty veneer is produced almost as a by-product. However, knotty veneer can also be produced from cheaper unpruned logs. Although none is, the model identifies clear veneer correctly as the cause of the requirement for pruned logs and tries to minimise this requirement within the market constraints.

Veneer production in this mill type is, like sawn timber production in small sawmills, quite sensitive to production costs. This sensitivity is most pronounced before the new capacity/rebuild comes on stream, with relatively narrow ranges (Appendix D) on the production cost variables (e.g. P272). Violating these ranges (particularly when increasing costs) usually results in capacity being shut-down. Sensitivity to changes in veneer price is not so pronounced, with fairly wide ranges associated with the veneer price variables (e.g. F2732). The veneer producer should focus its energies on reducing production costs while continuing the search for market niches for its products.

Reconstituted boards. Figures 6-11 and 6-12 show production and sales for MDF and OSB, the two types of reconstituted board produced in the model solution. Production of MDF doubles to 180 000 m^3/an over the

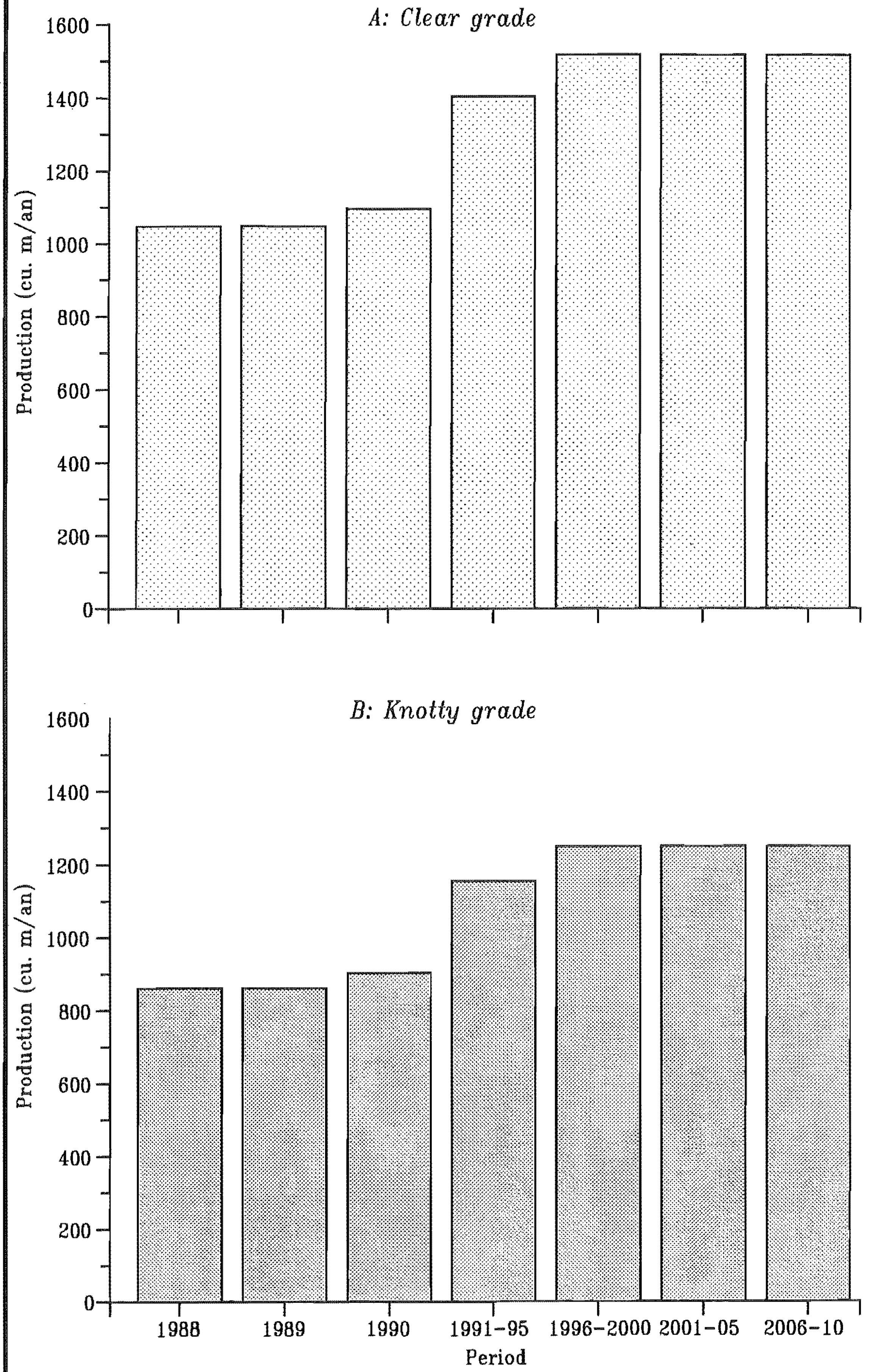

Figure 6-9. Annual production of veneer in Canterbury.

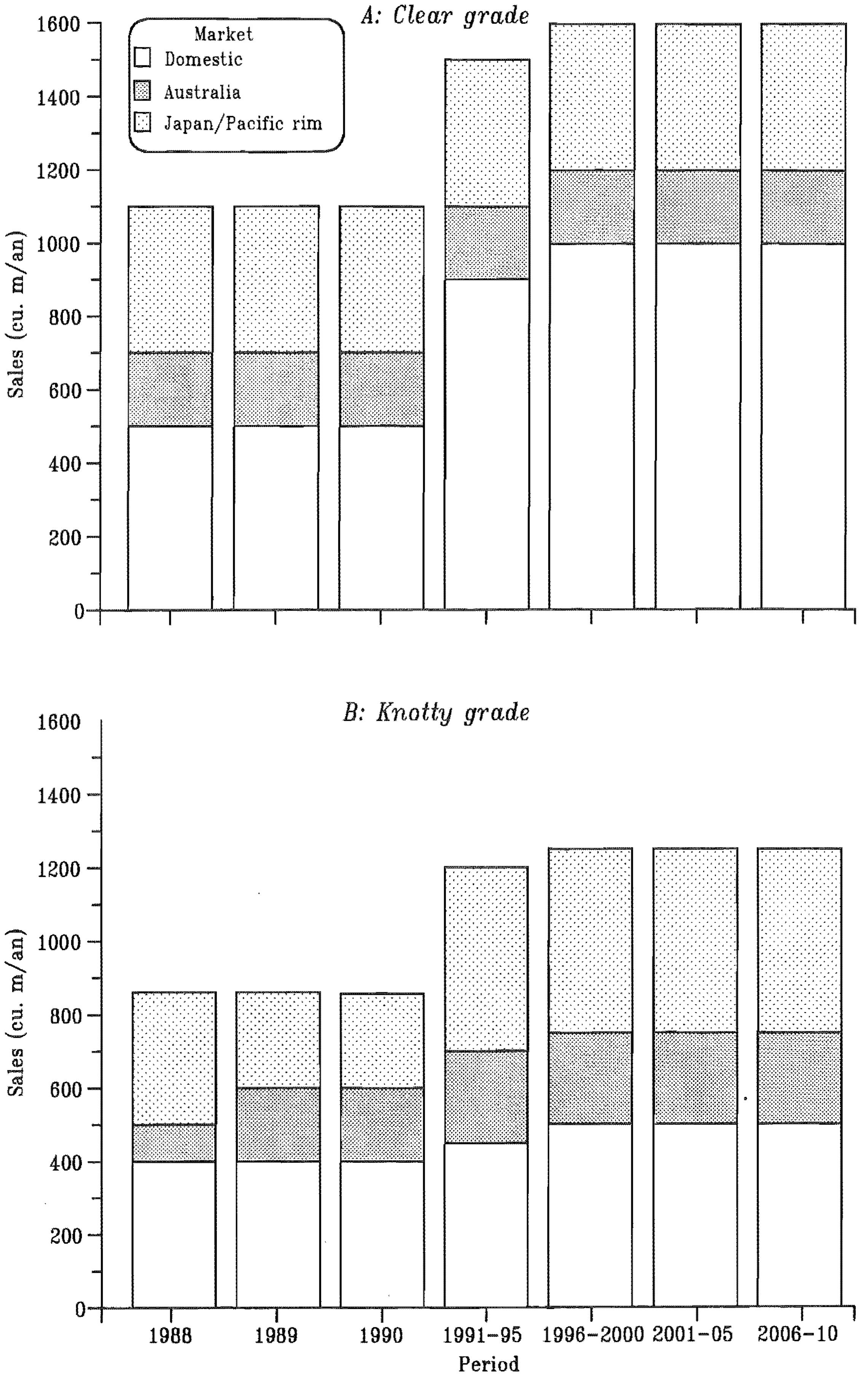

Figure 6-10. Annual sales of veneer from Canterbury.

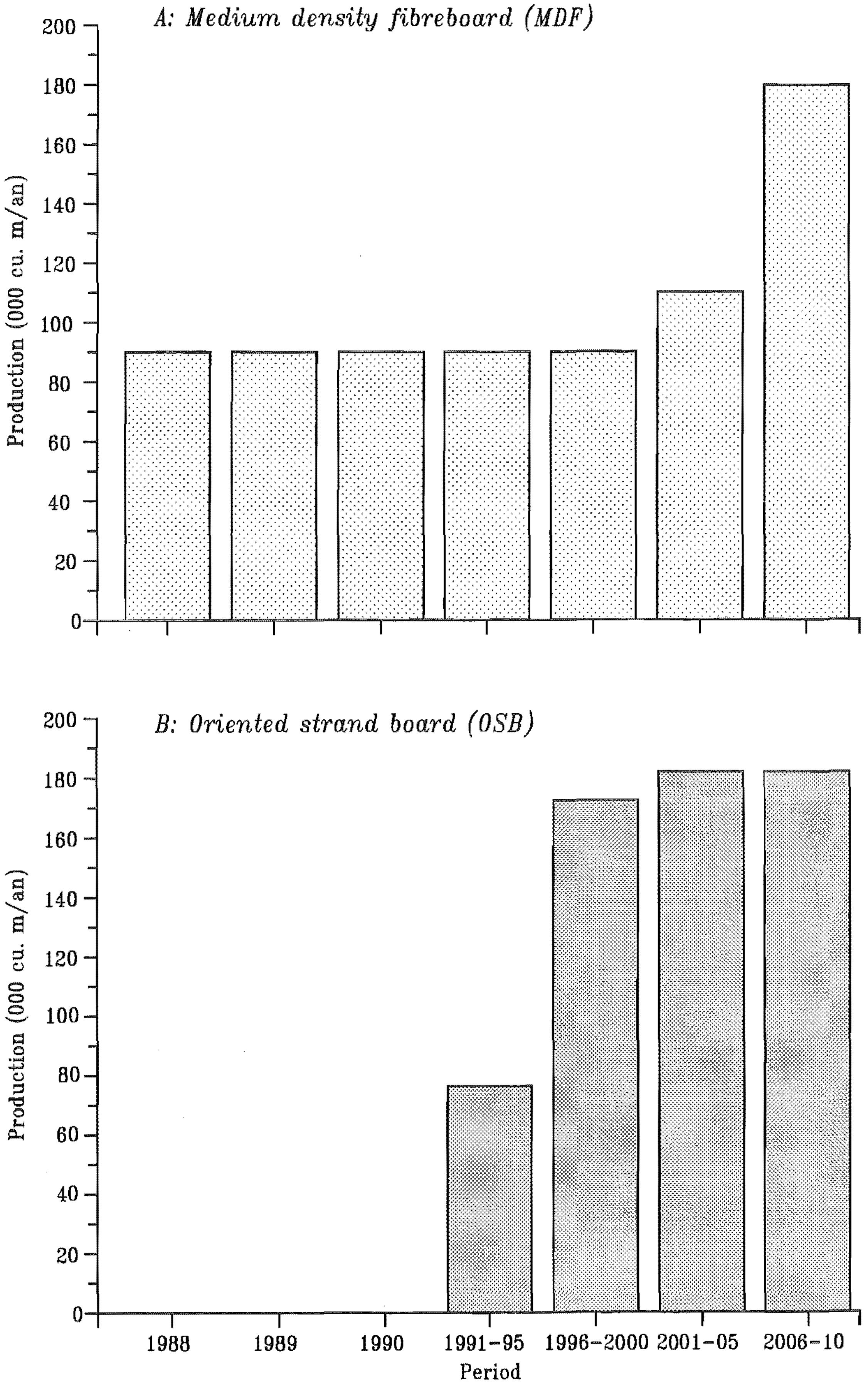

Figure 6-11. Annual production of reconstituted boards in Canterbury.

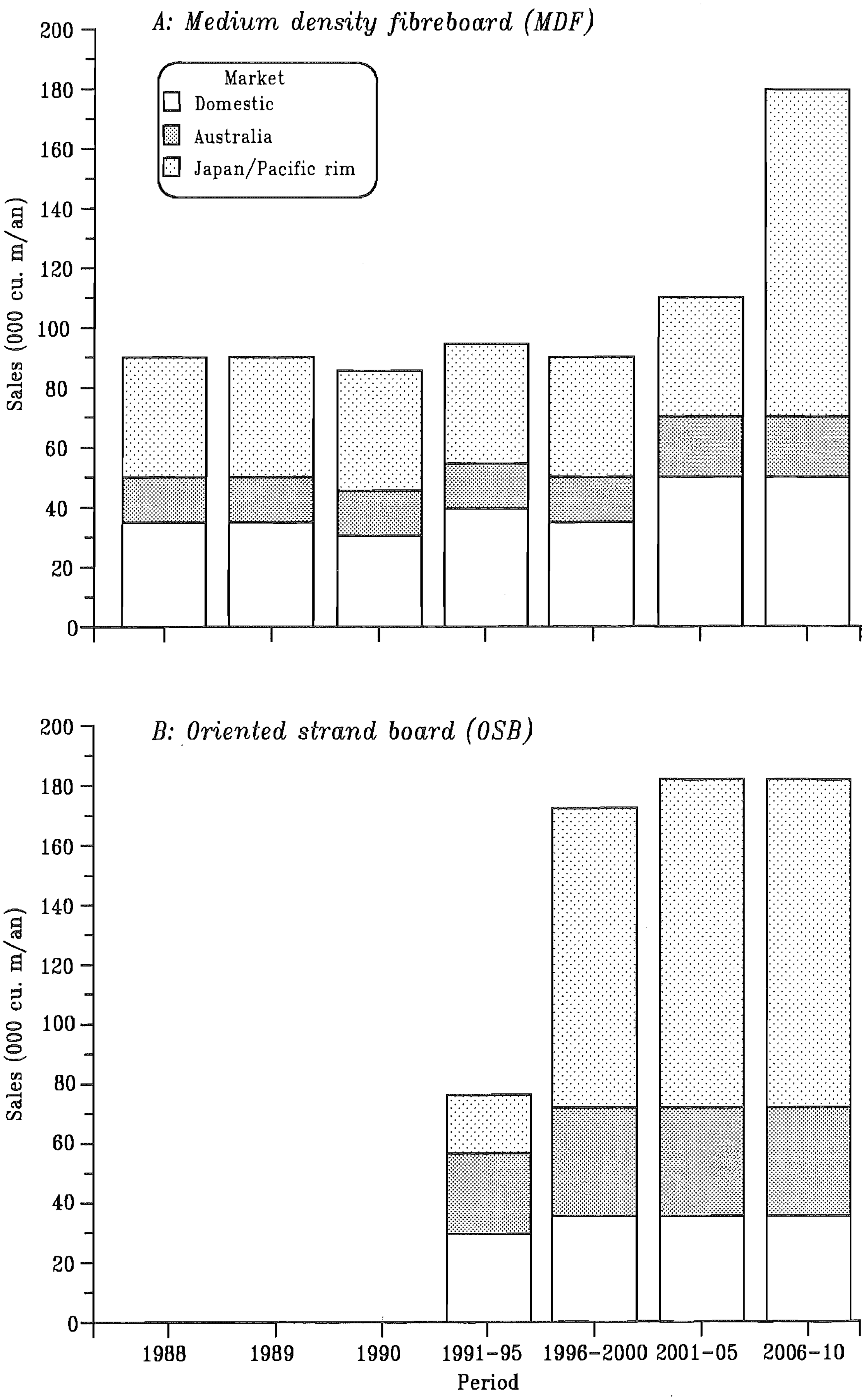

Figure 6–12. Annual sales of reconstituted boards from Canterbury.

horizon, following the introduction of a second plant in the penultimate period. OSB production increases to full capacity of 100 000 m^3/an by the sixth period. Both mill types supplement production with small quantities of chip imports (Table A-4).

Sales of MDF and OSB parallel production levels, for the most part remaining at upper bounds in the higher profit domestic markets. Exports to Australia and particularly to the high volume Pacific rim markets only rise to their upper bounds in the final periods, when capacity is available to allow the required production increases. The importance of these export markets in the development of the region's processing sector is marked: MDF exports rise from 60 to 72 per cent of production over the horizon, while exports of OSB grow to make up over 80 per cent of production. Clearly, the development of the region is dependent on continued access to both the Australian and (more importantly) the Pacific rim markets.

The high shadow prices associated with sales at upper limits (Table A-12) indicate the importance of these markets to the solution and to the region. Increasing market limits can lead to marginal profit increases of up to \$180/m^3, a clear indication of the value of marketing to increase sales in these regions. These shadow prices (and the industrial structure given in the optimal solution) remain valid over a fairly wide range of market limits, further indicating the importance of these products to the region. The solution is also less sensitive to changes in processing costs and product prices for MDF and OSB than the other products examined here, a result of the superior profitability of the reconstituted board products. Clearly, these are the products which should drive the development of the Canterbury wood processing sector into the next century.

6.3.5 Summary

The preceding sections indicate the type of analysis which can be carried out based on WPPM output. Some minor aspects of the solution, such as product and log storage, have not been discussed in detail. The full breadth of the solution output can be seen in the 20 pages of REPORT tables in Appendix A and the 54 pages of condensed sensitivity analysis summary from RESTART.LIS in Appendix D. The above analysis is an attempt to synthesize some of the main features of this longer output into a cohesive account of important issues.

The development of the region's wood processing industry could follow a number of different scenarios within the broad framework provided here. Many in the industry feel that Carter Holt Harvey, which already has substantial interests in the region (both the MDF and veneer plants are subsidiaries), will make a bid for one or more of the current State forests. If the company is successful with such a bid, construction of a sawmill to obtain maximum benefits from its forest holdings would be a logical progression, as would expansion of reconstituted board capacity. It is also possible that a consortium of the region's five largest sawmillers, who have a long tradition of bidding together for State wood supplies, could use their combined resources to purchase sufficient forest resources to ensure continuity of wood supplies to their mills. This could lead, in turn, to a rationalisation of sawmilling capacity such as that modelled here. Regardless, the information contained in this case study could prove helpful to any organisation considering purchasing Canterbury's State exotic forests.

Although no analysis of the effect of interest rate on the solution was undertaken here, its effect should not be overlooked. Lower real rates than that modelled here (7 per cent) would make capital investment in new processing capacity more attractive. It is essential that the model be revised and re-run if significant changes in real interest rates are expected. Current forecasts (e.g. Brash, 1989; Reserve Bank, 1988) predict real interest rates remaining close to current levels in the medium term, with longer term forecasts difficult to obtain. However, an indication of the effects of changing interest rates can be obtained from the price range analysis in Appendix D (RESTART.LIS), as changes in interest rates translate directly into changes in objective function coefficients. Those variables having narrow ranges within which their objective coefficients can vary will be most susceptible to changes in the interest rate.

Because of the nature of the SAS output files, analysis of the range summaries and sensitivity analysis in general may prove more troublesome than examination of the REPORT output, and should not be undertaken without expert guidance. Once the output *has* been analysed, there remains the task of evaluating the validity of such output (and hence the analysis to which it was subjected). Chapter 7 discusses the requirements of such evaluation and presents a brief assessment of this implementation of WPPM, in terms of both computer performance and output validity. It also identifies some prospects for further development of the WPPM system.

CHAPTER 7

EVALUATING AND REFINING WPPM

This chapter evaluates the performance and realism of the WPPM system, based on the limited application of the model reported here. Some potential revisions to the system are proposed in the second part, each of which would lead to enhanced utility and/or realism if implemented.

7.1 Evaluation

Evaluation of WPPM essentially consists of determining whether the system is suitable for the pupose(s) it was developed for. Since the primary objective of this research has been to produce a tool to aid strategic planning by and for the wood processing industry, full evaluation will only be possible following further use of the modelling system. However, the preliminary runs carried out and presented here allow a limited evaluation of the system to be made.

The first two specific objectives listed in Chapter 1, namely:

(i) to develop a methodology to coordinate resources, markets and processing capacity; and

(ii) to focus on the Canterbury region

were met in the construction of WPPM and by the case study, documented in the previous chapters. The third specific objective, compatibility with the structure of FORSEMODEL, was also met by construction. However, no formal linkage between the two models was established due to current software and hardware incompatibility. Furthermore, additional research into the nature of competition between different regions and processes (including log exports) for a range of log types produced from different silvicultural regimes will be necessary before meaningful integrated runs of the two models can be attempted.

The success of the WPPM system in attaining practical utility and realism (the final objective from Chapter 1) is evaluated in the next two sections. Section 7.1.1 deals with model performance (and thus utility) in terms of computer resources and data entry time. Model realism, defined as "the extent to which the model captures the dynamics of the sector of interest" (Gilless and Buongiorno, 1987), is evaluated by comparing short term model forecasts with actual industry statistics and forecasts in section 7.1.2.

7.1.1 Model performance

Table 7-1 outlines the computer resources required to run two sizes of WPPM problems, as well as the data input time. These data are specific to the VAX 6210 hardware at Canterbury (classified as a mini-computer); run time figures would be substantially reduced on more powerful computer systems. The complete solution statistics for the case study problem are attached in Appendix A.

Table 7-1. WPPM computer resources and data input time.

Run	Variables[1] I	Variables[1] C	Constraints	CPU time (sec)[2] R	CPU time (sec)[2] I	Data input time (hr)
1. Test runs	18	216	120	10	18	2.5
2. Case study	182	3078	1458	3900	40 140	29.5

Notes: 1. I = integer variables, C = continuous variables. Total variables = I + C.
2. R = solution time for relaxed problem, I = solution time for integer constrained problem (total solution time).

The case study problem is roughly ten times the size of the test runs described earlier. Solution times appear to increase exponentially with problem size, and appear particularly sensitive to the number of integer variables in the problem. The SAS solution software took approximately 40 times longer to solve the case study "relaxed" (i.e. non-integer constrained) problem than the smaller relaxed test run problems. The total solution time for the case study problem was more than 2000 times that of the test runs, however, indicating that the bulk of the CPU time used in such large-scale problems is devoted to the branch and bound algorithm which searches for feasible, and ultimately optimal, integer solutions. SAS options exist for terminating the algorithm when the best integer constrained solution is within a given range of the relaxed solution; such options can help to reduce run times.

The length of time required to input the data for problems appears to increase in a linear fashion with problem size. As discussed in Chapter 5, DATMAT decreases the time involved in this step substantially, particularly in large-scale problems. Analyses of the scope of the case study presented here would be practically impossible to carry out without the aid of such a data entry/matrix generation system. Clearly, the existence of DATMAT greatly enhances the usability of WPPM in large scale applications.

By far the most expensive component of Table 7-1 is CPU time. At the current University commercial charging rate of $2 per CPU minute, the case study runs would cost $1,340. Given the potential benefits of such modelling (see Chapter 6), and the recommended interval between model updates (at least one year), this expense does not appear unreasonable. The duration of runs for large-scale problems is recognised as a potential problem in the utilisation of the system, however, particularly where computer systems are shared among many users. In these cases, real time required to obtain a solution may greatly exceed the actual CPU time used.

Use of batch queues is strongly recommended for model runs of the scope of the case study.

A final practical concern is the amount of disk storage space required and/or available for storing the WPPM data base, matrix and output files. The data base itself can be stored relatively compactly; a 360 K floppy disk should provide adequate storage space for most applications (see Appendix C). The matrix and permanent SAS data set produced by DATMAT, however, require substantial disk space. This can be reduced if the SAS "named-input" option discussed in Chapter 5 is available, but otherwise the matrix must contain a coefficient for every variable in every constraint. This can generate huge data files for large problems - the case study matrix required 20 000 blocks of disk space on the Vax 6210 (20 to 30 360 K floppy disks), with the associated SSD file slightly larger. Future work on the model system should focus on adaptations to DATMAT which will allow it to take advantage of named input, which will hopefully be extended to Vax mini-computers in the near future. Finally, the standard output listing (WPPM.LIS or RESTART.LIS) can also become quite large when full sensitivity analyses are requested. The solution listing contains, by default, problem, variable, constraint, branch and bound and solution summaries, together with any requested sensitivity analyses. Using the NOPRINT option (see Chapter 5) allows much of this output to be avoided, since most of the relevant information is provided in the output from REPORT. The sample listing in Appendix D (RESTART.LIS) contains a sample page from each type of output summary listed above, together with the sensitivity analysis on all relevant variables (see Chapter 6).

Large problem sizes and long run-times are trade offs that need to be accepted in detailed long range sectoral modelling such as this. Despite the difficulties mentioned above, the model was successfully run on a busy shared-time mini-computer which has been used to full capacity since its installation. Thus, although improvements in model structure or software resulting in decreased disk storage and CPU requirements should continue to be sought, the current prototype has proven itself usable in a realistic computing environment.

7.1.2 Comparison with industry statistics

Production statistics for existing Canterbury wood products for 1988 agree well with those generated by the model (Table 7-2). This is not unexpected, as the wood shortages currently being experienced by the region preclude major changes in the short term. The primary reason for comparing the model results with base year data is to ensure that the model is behaving correctly and generating realistic solutions. Table 7-2 shows that the base period solution is realistic, while a careful examination of Appendix A reveals no obvious discrepancies in the output for other periods. The telephone follow-up (carried out in late 1988) to the earlier personal survey revealed that 2 small mills had closed since the earlier survey, one in Christchurch and one in rural Canterbury. WPPM suggested the closure of one small Christchurch mill in 1988, with 2 small rural mills earmarked for closure in 1989. Although local millers do not expect any further closures this year, most were sure that the introduction of a new mill (such as that suggested to begin production by 1990 in WPPM) would have an adverse effect on existing operations, leading to several closures in keeping with those modelled.

Table 7-2. Selected WPPM output and industry statistics for 1988.

Item		WPPM[1]	Actual
Production (m^3):	sawntimber	93 850	95 000
	veneer	1909	1800
	chips[2]	79 807	60 000
	MDF	90 000	90 000
Capacity util-isation (%):	sawntimber	82	80
	veneer	95	90
	MDF	100	100
Exports (% of total sales):	sawntimber	25	23
	veneer	55	50
	MDF	61	66
Employment (man-years)		388	401

Notes: 1. WPPM results derived from Appendix A; actual results derived from telephone survey update.
2. The discrepancy in chip production is due to the model assumption that all mills have the capability to produce chips.

As an additional check on the validity of the case study solution, and thus the model itself, two local experts were briefly consulted (Hawkins, *pers. comm.* 1988b; Clifton, *pers. comm.* 1988). Both were somewhat skeptical regarding two reconstituted board mills starting operations within twenty years, but conceded that it was indeed possible, particularly if market conditions were favourable. While it was felt that other regions with larger forest resources might be more likely candidates for establishing these plants, it should be noted that Canterbury already has an established infrastructure for harvesting and transporting its forest products and that the Plains forests are particularly suited to use for reconstituted board manufacture, with the higher risk of windblow. Other aspects of the case study solution were by and large deemed feasible, particularly with the looming prospect of Carter Holt Harvey (parent company of both the veneer and MDF plants in Canterbury) buying substantial state forest resources in the region. Although such consultation with local experts can be difficult to arrange, it is a worthwhile exercise leading to enhanced confidence in model results.

Because of its long term nature and the complexity of modelled interactions, the only real way to validate a model such as WPPM is to use it. Comparison of model output with historical patterns of development may not be helpful, as there is no easy way of determining whether such historical development was in fact optimal (as that proposed by the model will always be, by definition). Thus, any future use of the model should be carefully documented in terms of the resulting solution and its perceived reliability and/or validity, both at the time of running the model and at fixed intervals thereafter. Such records would allow a more critical evaluation of the model's performance in a range of applications.

7.2 Refinements

Although the current model appears to capture the dynamics of the wood processing sector and to provide realistic strategic scenarios, there are several aspects of the system which, if suitably modified or corrected, would lead to greater realism and utility. These aspects fall into the general categories of model structure and model output. Each category, discussed below, should be given due attention in any further development of the WPPM system.

7.2.1 Model structure

Extending the model to incorporate a wider range of products (primary or secondary) will be a concern in any further development and use, particularly in regions other than Canterbury. Introduction of secondary processes such as furniture could prove difficult because of the range of different products involved. In most cases, however, introduction of additional existing or newly emerging processes will simply involve collecting the relevant processing and market data. The existing model structure should be able to cope with most wood processing options. However, some, such as the co-generation of energy from wood waste, may require the introduction of new variables (to decide, for instance, on the optimal mix of fuel and chip wood). If fuel from wood is assumed to be derived solely from waste, however, and this waste is a known percentage of log or chip input, then energy derived from co-generation can be modelled as an output using the non-wood input-output constraints. Regardless of which option is chosen, model size will increase with the number of processes modelled. It is important, however, that all feasible processes (existing and emerging) are included in the model framework to allow true optimisation over all processing options.

Increases in model size raise concerns about computer memory requirements and solution times. Developments in the SAS software used to develop WPPM should be incorporated as they arise, particularly with respect to the named input option discussed earlier. Consideration should be given to developing a recursive version of WPPM for large-scale applications - removing the time dimension can reduce problem size by a factor of the number of periods considered, resulting in a series of smaller problems. This approach shows more promise than that of decomposition, both in terms of simplicity and enhanced output capabilities (see section 7.2.2).

There are now a number of powerful linear programming packages available for personal computers (PC's), some of which allow users to incorporate the LP solution code into their own applications packages (Sharda, 1988). The SAS software used here (PROC LP) is also likely to be available on personal computers shortly. A PC version of WPPM should be considered, particularly as the computer industry is moving toward complete integration between mainframe and micro-computers (Miller, 1988). Such integration would allow storage of the large WPPM data files on a central mainframe, while processing could be carried out on PC's.

The representation of exchange rate functions in WPPM should be developed further from that presented in the case study to incorporate functions for each product/country combination. Although the Reserve Bank predicts only small changes in the exchange rate in the medium term (Brash, 1988), exports to some markets (particularly Australia) are very sensitive to exchange rate. Individual functions, based on time series of appropriate exchange rate and export statistics, would represent this sensitivity more realistically than the approach taken in Chapter 6.

The development of an iterative pricing mechanism for log prices in WPPM should also be considered in any future work. Such a mechanism would involve the incorporation of supply and demand functions for the various log grades modelled, and would require further research into the nature of competition for logs between different processes and its effect on price. Such a mechanism could also be extended to determine prices of final and intermediate products, based on demands generated within the model. The approach taken would likely be a variation of the price endogenous methodolgy described briefly in Chapter 3 (Gilless and Buongiorno, 1987). The data requirements for such an approach are substantial (e.g. price and income elasticities of demand, forecasts of population growth and *per capita* income, *et cetera*), and are not readily available. Nonetheless, efforts should be made to incorporate the effects of supply and demand on commodity prices in future versions of WPPM, at least in a rudimentary fashion.

7.2.2 Model output

As stated in Chapter 5, WPPM sensitivity analysis output, with the exception of constraint shadow prices which are included in the DUAL.SSD data file, can only be obtained from the standard SAS solution output (e.g. RESTART.LIS). As mentioned in Chapter 6, this can be confusing and frustrating when attempting to interpret such output (see Appendix D). Future work on the model system should attempt to integrate sensitivity analysis output with the output from REPORT, resulting in a single output file containing all relevant results. Such integration would be greatly facilitated if permanent data files containing the ranging data and other sensitivity analyses not included elsewhere could be generated within SAS.

A second potential revision to WPPM output would result in incomes being generated for each period and for each industry or mill type.

Such output would allow the contribution of any period and/or mill type to overall profitability to be assessed. Profitability by mill type can be obtained only by aggregating all production, sales, *et cetera* for that mill type and calculating profits based on the relevant objective function coefficients. This could be carried out by a relatively complicated SAS program capable of manipulating the solution data file (PRIMAL.SSD). Periodic incomes could be obtained in a similar manner, or could be obtained directly if a recursive programming approach (see above) was implemented.

Although the current model is clearly useful as is, further development with respect to any of the above refinements will lead to improved modelling utility and reliability. Perhaps the most important refinement to be borne in mind by potential users is, however, the regular updating of the model data base. If adequate revision of the data base is not carried out, other revisions (such as those just listed) will be rendered ineffectual.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The New Zealand forest processing industry needs to expand substantially over the next fifteen years if it wishes to capitalise on the increasing supplies of roundwood soon to become available. An expansion of the requisite scale demands, in addition to the unique planning needs of all forestry enterprises, careful consideration and analysis of alternative strategies. Undertaking such planning and analysis for individual plants or even products is unlikely to produce an optimal (or even desirable) industrial structure. This objective can be achieved only by considering the sector as a whole, and its interactions with other sectors of the economy.

The analysis of an entire sector of an economy is a complex and demanding task. The WPPM system developed here facilitates such analyses by examining in detail one aspect of the New Zealand forest sector - regional processing. The approach taken, that of examining production in homogeneous mill types, shows promise, allowing a more detailed examination of the wood processing sector than that possible with many more traditional sector models. This narrowing of focus from traditional sectoral planning models has also been applied to the spatial element in WPPM, with the focus on geographical regions of the country rather than on the economy as a whole. Since the characteristics of timber supply, wood processing, and to some extent markets are more homogeneous within than between regions, such a breakdown serves to increase the homogeneity of mill types, thereby improving the model's reliability.

Although only one region was examined in detail, this research study found that many of the country's wood processors lack a range of prerequisites for long range strategic planning at the individual plant level. These missing prerequisites include long term market forecasts, knowledge of non-traditional markets, and awareness of technological innovation. Clearly, if such information is absent at the individual level, it will be difficult to obtain at the level required for coordinated sectoral planning of the country's wood using industry. Moreover, there is an apparent lack of awareness of the need for such coordinated planning among some users of wood. WPPM forces users to confront data limitations in the strategic planning process, and can therefore improve both the quality and quantity of such planning carried out by and for wood processors.

A particularly useful feature of WPPM is the insights it can provide during collection and development of the underlying data base. Data such as those collected for the case study here comprise a synthesis of resource, processing and market information and predictions. Few studies of the New Zealand forest sector incorporate such a comprehensive data base, particularly with respect to the costs and conversions associated with wood processing. The data base in Appendix C, consisting of the 11 products actually modelled plus others not included in the Canterbury case study (export squares, hardboard, softboard, chemical and mechanical pulps, newsprint and multiwall/corrugating paper products), should provide a good starting point and reference for future modelling efforts. Regardless of the scope of such efforts, however, it is strongly recommended that user-specific data bases are developed. Aside from improving the reliability of model solutions, this process can contribute to a greater understanding of the system being modelled, and as mentioned above, to more meaningful strategic planning.

The mathematical structure of WPPM is such that new or additional processes can be introduced without re-writing the LP code. DATMAT, the custom built matrix generator, allows the user to specify not only the number and type of processes to be modelled but also the technical coefficients and limits for processing, resource supplies and markets. This flexibility is an important feature of WPPM, allowing users to formulate problems relevant to their particular situation, using the best data available to them. As mentioned above, significant insights can be gained during problem formulation. WPPM enhances the development and extension of such insights by allowing for alternative formulations, objective functions, sensitivity analyses, *et cetera*.

The flexibility in the structure of WPPM is complemented by its potential portability between different computer systems. The software used to develop the model (FORTRAN 77 for DATMAT, SAS-OR for solving the WPPM mixed integer program and base SAS software for REPORT) is available on a wide range of computer systems. It would also be relatively easy to implement the model on any other LP package with integer programming capability, although DATMAT and REPORT are necessarily restricted to use with the SAS system. The impending release of SAS-OR for IBM compatible micro-computers means that the portability of the system could be greatly enhanced, albeit at the sacrifice of some model detail. Such a sacrifice would be worthwhile, however, if it resulted in placing the power of WPPM more readily in the hands of the mill managers and decision-makers it is designed to assist.

The analysis carried out in Chapter 6 illustrates the type of application for which WPPM was designed: regional sectoral planning. The Canterbury region, while not a major wood producer, faces a number of problems similar to the major producing regions in planning the rational development of its forest industry. The case study model highlighted some of these and their interactions: they include a labour intensive/capital extensive industrial structure, a shortage of raw material well into the next decade and a lack of liquid capital for investment in new processing capacity.

Modelling the Canterbury region indicates that a near doubling of current employment levels is possible from the proposed expansion of the wood processing industry. One new production process should be introduced (OSB) early in the next decade, accompanied by substantial increases in production of the region's existing wood products (veneer, sawntimber and medium density fibreboard) over a 23 year planning horizon. It is the increase in the manufacture of reconstituted boards that provides the bulk of this development. Not all of the region's wood supplies are utilised in this industrial development, however, with substantial supplies of pruned butt logs available for export from the late 1990's onward.

Wood shortages in the first four periods (to 1995) are pronounced, however, and act to limit production. The shadow prices associated with the wood supply constraints for these periods indicate the sensitivity of the model solution to wood supply in the early periods. For instance, if the availability of unpruned logs from plains forests in 1990 is increased or decreased from the forecast level of 12 900 m^3, the overall regional profit changes in the same direction by \$411/m^3 (over the range 9100 - 13 100 m^3). While few processors would be willing to pay this amount for an extra cubic metre of this log type, the value nonetheless represents the economic "opportunity cost" of this type of wood to the region as a whole in this period. Such information could prove valuable to processors considering acquiring State forests, as discussed in Chapter 6.

Exports of forest products play an important role in the region's industrial expansion, more than tripling in total volume over the planning horizon. Exports of panel products make up the bulk of this increase, expanding four fold. Sawntimber exports increase more slowly, only rising by some 50 per cent. This is due primarily to the offsetting of new capacity by plant closures. Australia remains the major export market for sawntimber producers, while Pacific Rim countries receive the bulk of exported panel products.

Although the case study serves primarily as a demonstration of the use of WPPM, the results are by no means trivial. The prospect of two new reconstituted board mills being constructed in Canterbury in the next 20 years may seem far-fetched, but the model indicates that such development is not only feasible, but profitable as well. Such results could help to attract badly needed investment capital to the sector.

The Canterbury case study illustrates the large number of variables that influence a region's forest industry. The relationships among these variables can be complex, even in regions such as Canterbury with relatively simple industrial structures and development potentials. WPPM allows for a structured analysis of these relationships and provides a tool for planners to evaluate different development strategies in ways not otherwise possible. The predictions and strategies resulting from a WPPM run should not, however, be viewed as absolute. The model indicates desirable strategies within the limits and assumptions set by the user. Given a reliable data base, the utility of a model such as WPPM should be gauged by its ability to predict consequences of taking one or more decisions in the sector of interest. Preliminary evaluation of WPPM indicates that its predictions are consistent with current trends in the Canterbury region (e.g. the increasing concentration of production in the sawmilling industry; the increasing importance of reconstituted board manufacturing). Much work remains to be done in evaluating the model's utility for other regions and applications.

As alluded to above, there remains substantial scope for improvement in the model structure and its underlying data base, particularly with respect to sectoral applications. Primary consideration should be given to a more rigorous method of modelling the interaction between the demand for logs (generated by the model) and their prices (currently provided exogenously). More work also needs to be done exploring the competition between different wood processors for raw materials and the effect this has on log prices. The inclusion of other segments of the wood processing sector should also be given priority in any revision of WPPM. This will entail primarily the collection of relevant data, as the model structure can accommodate any number of products. Likely candidates for future inclusion are the furniture, wood preservation and wood alcohol industries. Because of practical limitations on model size, it may be desirable to develop separate models for primary and secondary wood processing within a region. In addition to new processes, data for existing processes should be regularly updated and improved. Improvements in the quality of data with respect to output of various products from different log grades is essential and would allow a more realistic representation of industries producing multiple products. The existing model size is governed mainly by hardware constraints as reported in Chapter 5. Increasing the size of the model through introducing new processes or breaking down existing products into more realistic aggregations may increase excessively the cost of running WPPM. Consideration should then be given, therefore, to the use of decomposition and/or recursion techniques which were discussed in Chapter 3.

The research reported here confirms the generally agreed notion that in future the New Zealand forest sector will be export driven, and it indicates how much work remains to be done to quantify the characteristics of potential export markets for New Zealand forest products. The preliminary investigations reported here need to be extended to include an analysis of other countries and products via detailed market studies. These studies should aim to forecast demand and prices for the full range of export products in the major importing countries or regions. Improvements in export forecasts will naturally enhance the reliability of WPPM predictions.

One of the goals of this research has been to produce a methodology that could be used in conjunction with FORSEMODEL (discussed in Chapter 2) to generate optimum strategies for the entire forest sector. The structure of WPPM has been designed to allow such a linkage, but no formal linkage runs have been undertaken because of current software and hardware incompatibility. Even if such difficulties were resolved, however, there remains a lack of data on the competition between different industries (and export markets) for log supplies of variable quality produced from a range of silvicultural regimes. The proposed introduction of new log grades by the FRI should allow a more rigorous examination of the nature of such competition, but much work remains to be done to achieve widespread acceptance of this grading scheme. Before WPPM and FORSEMODEL can be used together as hoped, further studies must be undertaken to quantify the nature and extent of roundwood interdependencies in the New Zealand forest sector.

Regardless of any shortcomings, WPPM represents a substantial advance for New Zealand wood processors and forest planners currently facing a variety of strategic planning problems. The growth of the industry, and to some extent the entire economy, depends on these problems being carefully addressed and resolved in a rational and coordinated fashion. WPPM provides a methodology for examining and analysing the complex interactions that characterise the wood processing industry, and can thus assist long range, strategic decision-making.

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APPENDIX A

REPORT OUTPUT FOR THE CANTERBURY CASE STUDY

The output tables and solution summary on this and the following pages are reproduced from the actual REPORT output generated by WPPM for the Canterbury case study. Figures for the final period (2011-15) were not considered, as discussed in Chapter 6. The tables include only rows for items having at least one non-zero value over the planning horizon. "SH. PRICE" in Tables A-7 to 13 refers to the shadow price or reduced cost of the associated constraint. All other abbreviations are consistent with those used in the text. A listing of the tables included in this appendix follows.

Solution Summary

Continuous variables	3078	Relaxed[1] CPU (sec)	3900
Integer variables	182	Total CPU (sec)	40 140
Constraints	1457	Optimal solution	$257,350,898

1."Relaxed" refers to the non-integer constrained continuous problem; "Total" incorporates the CPU time required to implement the branch and bound algorithm to solve the integer constrained problem.

LOG TYPE PRUNED

TABLE 1. LOCAL LOG PURCHASES (M3)		PERIOD						
MILLTYPE	FOREST	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
SAWLC	PLAINS	0	7982	0	8214	11488	0	0
	FOOTHILLS	0	0	0	9800	0	0	0
	TOTAL	0	7982	0	18014	11488	0	0
SAWSC	PLAINS	19500	2070	9543	0	0	0	0
	FOOTHILLS	1059	2070	0	0	0	0	0
	TOTAL	20559	0	9543	0	0	0	0
SAWSR	FOOTHILLS	0	6200	8000	0	0	0	0
	TOTAL	0	6200	8000	0	0	0	0
VENSC	PLAINS	0	3748	4357	4586	5435	5435	5435
	FOOTHILLS	3741	0	0	0	0	0	0
	TOTAL	3741	3748	4357	4586	5435	5435	5435

LOG TYPE UNPRUNED

TABLE 1. LOCAL LOG PURCHASES (M3)		PERIOD						
MILLTYPE	FOREST	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
SAWLC	PLAINS	19000	13000	12900	0	30500	0	0
	FOOTHILLS	0	0	0	11900	0	0	0
	PRIVATE	74895	68966	0	17462	0	52085	41667
	TOTAL	93895	81966	12900	29362	30500	52085	41667
SAWLR	PLAINS	0	0	0	0	0	41633	0
	FOOTHILLS	0	0	0	0	0	29200	0
	PRIVATE	0	0	88388	73338	83333	12500	125000
	TOTAL	0	0	88388	73338	83333	83333	125000
SAWSC	PLAINS	0	5800	0	15200	18300	0	23105
	PRIVATE	28914	38234	0	0	0	49105	0
	TOTAL	28914	44034	0	15200	18300	49105	23105
SAWSR	PLAINS	0	0	0	0	0	7667	0
	FOOTHILLS	4600	0	7300	0	23300	0	0
	PRIVATE	17991	0	11912	0	15967	0	65217
	TOTAL	22591	0	19212	0	39267	7667	65217

LOG TYPE OTHER

TABLE 1. LOCAL LOG PURCHASES (M3) MILLTYPE	FOREST	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
		PERIOD						
SAWLC	PLAINS	0	0	0	15000	29600	0	0
	FOOTHILLS	0	0	7300	0	0	0	0
	PRIVATE	0	0	26700	0	0	0	0
	TOTAL	0	0	34000	15000	29600	0	0
SAWLR	PRIVATE	0	0	0	4007	0	0	0
	TOTAL	0	0	0	4007	0	0	0
SAWSC	PLAINS	10900	11500	13400	0	0	5609	33423
	TOTAL	10900	11500	13400	0	0	5609	33423
SAWSR	FOOTHILLS	2700	5800	0	12200	0	25766	0
	PRIVATE	23600	26700	0	18393	0	35800	0
	TOTAL	26300	32500	0	30593	0	61566	0
MDFLR	PLAINS	0	0	0	0	0	38991	17177
	FOOTHILLS	0	0	0	0	0	634	29400
	PRIVATE	0	0	0	0	0	0	56200
	TOTAL	0	0	0	0	0	39625	102777
OSBLR	FOOTHILLS	0	0	0	0	22800	0	0
	PRIVATE	0	0	0	0	28000	0	0
	TOTAL	0	0	0	0	50800	0	0

LOG TYPE RESIDUAL

TABLE 1. LOCAL LOG PURCHASES (M3) MILLTYPE	FOREST	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
		PERIOD						
CHIPSR	PRIVATE	0	0	4438	0	0	0	0
	TOTAL	0	0	4438	0	0	0	0
MDFLR	PLAINS	25900	25770	35600	17547	24472	7700	66700
	FOOTHILLS	6300	20800	21400	33100	0	52800	59900
	PRIVATE	45800	49300	47562	0	52100	0	0
	TOTAL	78000	95870	104562	50647	76572	60500	126600
OSBLR	PLAINS	0	0	0	22653	41328	81200	36500
	FOOTHILLS	0	0	0	0	51400	0	0
	PRIVATE	0	0	0	45100	0	67800	110000
	TOTAL	0	0	0	67753	92728	149000	146500

TOTAL, ALL LOG TYPES

TABLE 1. LOCAL LOG PURCHASES (M3) MILLTYPE	FOREST	PERIOD 1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
SAWLC	PLAINS	19000	20982	12900	23214	71588	0	0
	FOOTHILLS	0	0	7300	21700	0	0	0
	PRIVATE	74895	68966	26700	17462	0	52085	41667
	TOTAL	93895	89947	46900	62376	71588	52085	41667
SAWLR	PLAINS	0	0	0	0	0	41633	0
	FOOTHILLS	0	0	0	0	0	29200	0
	PRIVATE	0	0	88388	77346	83333	12500	125000
	TOTAL	0	0	88388	77346	83333	83333	125000
SAWSC	PLAINS	30400	13570	22943	15200	18300	5609	56528
	FOOTHILLS	1059	5800	0	0	0	0	0
	PRIVATE	28914	38234	0	0	0	49105	0
	TOTAL	60373	57674	22943	15200	18300	54714	56528
SAWSR	PLAINS	0	0	0	0	0	7667	0
	FOOTHILLS	7300	12000	15300	12200	23300	25766	0
	PRIVATE	41591	26700	11912	18393	15967	35800	65217
	TOTAL	48891	40700	27212	30593	39267	69233	65217
VENSC	PLAINS	0	3748	4357	4586	5435	5435	5435
	FOOTHILLS	3741	0	0	0	0	0	0
	TOTAL	3741	3748	4357	4586	5435	5435	5435
CHIPSR	PRIVATE	0	0	4438	0	0	0	0
	TOTAL	0	0	4438	0	0	0	0
MDFLR	PLAINS	25900	25770	35600	17547	24472	46691	83877
	FOOTHILLS	6300	20800	21400	33100	0	53434	89300
	PRIVATE	45800	49300	47562	0	52100	0	56200
	TOTAL	78000	95870	104562	50647	76572	100125	229377
OSBLR	PLAINS	0	0	0	22653	41328	81200	36500
	FOOTHILLS	0	0	0	0	74200	0	0
	PRIVATE	0	0	0	45100	28000	67800	110000
	TOTAL	0	0	0	67753	143528	149000	146500

LOG TYPE PRUNED

TABLE 2. LOG IMPORTS AND STORAGE		PERIOD 1988	1989	1990	1991-95
CATEGORY	MILL TYPE				
LOG IMPORTS (M3)	SAWLC	0	0	0	370
	SAWSC	5000	0	0	0
	SAWSR	0	5000	5000	0
LOG STORAGE (M3)	SAWSC	0	807	954	0
	SAWSR	0	0	800	0
	VENSC	0	0	436	0

LOG TYPE UNPRUNED

TABLE 2. LOG IMPORTS AND STORAGE		PERIOD				
		1988	1989	1990	1991-95	1996-2000
CATEGORY	MILL TYPE					
LOG IMPORTS (M3)	SAWLC	0	7500	7500	10000	12500
	SAWSC	7500	0	0	0	0
LOG STORAGE (M3)	SAWLC	7500	8197	0	0	0
	SAWLR	0	0	6155	0	0
	SAWSC	5000	0		0	0

LOG TYPE OTHER

TABLE 2. LOG IMPORTS AND STORAGE		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
CATEGORY	MILL TYPE							
LOG IMPORTS (M3)	SAWLC	0	0	5000	7500	0	0	0
	SAWSR	5000	5000	0	0	496	0	0
	MDFLR	0	0	0	0	0	10000	12500
	OSBLR	0	0	0	0	9504	0	0
LOG STORAGE (M3)	SAWLC	0	0	3400	0	0	0	0
	SAWSC	0	0	1340	0	0	0	0

LOG TYPE RESIDUAL

TABLE 2. LOG IMPORTS AND STORAGE		PERIOD					
		1988	1990	1991-95	1996-2000	2001-05	2006-10
CATEGORY	MILL TYPE						
LOG IMPORTS (M3)	CHIPSR	0	7500	0	0	0	0
	MDFLR	7500	0	10000	12500	0	0
	OSBLR	0	0	0	0	12500	15000
LOG STORAGE (M3)	CHIPSR	0	444	0	0	0	0
	MDFLR	0	10456	0	0	0	0

TOTAL, ALL LOG TYPES

TABLE 2. LOG IMPORTS AND STORAGE		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
CATEGORY	MILL TYPE							
LOG IMPORTS (M3)	SAWLC	0	7500	12500	17870	12500	0	0
	SAWLR	0	0	0	0	0	0	0
	SAWSC	12500	0	0	0	0	0	0
	SAWSR	5000	10000	5000	0	496	0	0
	CHIPSR	0	0	7500	0	0	0	0
	MDFLR	7500	0	0	10000	12500	10000	12500
	OSBLR	0	0	0	0	9504	12500	15000
LOG STORAGE (M3)	SAWLC	2500	8197	3400	0	0	0	0
	SAWLR	0	0	6155	0	0	0	0
	SAWSC	5000	807	2294	0	0	0	0
	SAWSR	0	0	800	0	0	0	0
	VENSC	0	0	436	0	0	0	0
	CHIPSR	0	0	444	0	0	0	0
	MDFLR	0	0	10456	0	0	0	0

TABLE 3. ANNUAL INTERMEDIATE PRODUCT (CHIP) FLOWS (M3)	PERIOD						
	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
	SINK MILL	SINK MILL	SINK MILL	SINK MILL	SINK MILL	SINK MILL	SINK MILL
	MDFLR	MDFLR	MDFLR	MDFLR	MDFLR	MDFLR	MDFLR
SOURCE MILL							
SAWLC	35488	35488	22469	29276	29431	20350	14583
SAWLR	0	0	34032	29225	29167	29167	43750
SAWSC	23534	19337	7724	6298	0	19697	20350
SAWSR	19401	17532	11308	11301	14315	24924	23478
VENSC	1384	1387	1451	1858	2011	2011	2011
CHIPSR	0	0	10000	905	0	0	0
ALL SOURCES	79807	73505	86984	78864	74923	96148	104162

MILL TYPE VENSC

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	VENEER A	52	52	55	39	76	76	76
	TOTAL	52	52	55	39	76	76	76
PRODUCTION (M3)	CHIPS	1384	1387	1451	1858	2011	2011	2011
	VENEER A	1048	1049	1098	1406	1522	1522	1522
	VENEER B	861	862	902	1155	1250	1250	1250
	TOTAL	3293	3298	3451	4419	4783	4783	4783
PRODUCT STORAGE (M3)	VENEER A	0	2	55	0	0	0	0
	VENEER B	0	0	45	0	0	0	0
	TOTAL	0	2	100	0	0	0	0

MILL TYPE SAWLC

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	TIMBER B	1369	1113	778	963	998	640	562
	TOTAL	1369	1113	778	963	998	640	562
PRODUCTION (M3)	CHIPS	35488	35488	22469	29276	29431	20350	14583
	TIMBER A	8112	6957	3356	8154	6970	2795	3333
	TIMBER B	27377	22260	15553	19267	19960	12055	11250
	TIMBER C	4512	10783	11194	12578	13070	10150	5417
	TOTAL	75488	75488	52571	69276	69431	45350	34583
PRODUCT STORAGE (M3)	TIMBER A	0	0	168	0	0	0	0
	TIMBER B	1369	0	0	0	0	0	0
	TIMBER C	0	0	560	0	0	0	0
	TOTAL	1369	0	727	0	0	0	0

MILL TYPE SAWLR

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		PERIOD				
		1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	TIMBER B	1313	1117	1125	1125	0
	TOTAL	1313	1117	1125	1125	0
PRODUCTION (M3)	CHIPS	34032	29225	29167	29167	43750
	TIMBER A	7779	6480	6667	6667	10000
	TIMBER B	26253	22345	22500	22500	33750
	TIMBER C	5968	11176	10833	10833	16250
	TOTAL	74032	69225	69167	69167	103750
PRODUCT STORAGE (M3)	TIMBER A	389	0	0	0	0
	TIMBER C	298	0	0	0	0
	TOTAL	687	0	0	0	0

MILL TYPE SAWSC

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	TIMBER B	668	909	197	211	175	673	640
	TOTAL	668	909	197	211	175	673	640
PRODUCTION (M3)	CHIPS	23534	19337	7724	6298	6755	19697	20350
	TIMBER A	6809	3933	2026	1120	1610	3058	2055
	TIMBER B	13351	18093	3942	4225	3504	13454	12795
	TIMBER C	9840	4332	3633	2672	3244	8487	10150
	TOTAL	53534	47695	17326	14315	15113	44697	45350
PRODUCT STORAGE (M3)	TIMBER A	0	0	101	0	0	0	0
	TIMBER B	227	0	0	0	0	0	0
	TIMBER C	0	0	182	0	0	0	0
	TOTAL	227	0	283	0	0	0	0

MILL TYPE SAWSR

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	TIMBER B	611	478	332	327	496	742	815
	TOTAL	611	478	332	327	496	742	815
PRODUCTION (M3)	CHIPS	19401	17532	11308	11301	14315	24924	23478
	TIMBER A	1981	2878	3471	764	2366	1691	3913
	TIMBER B	12221	9555	6633	6544	9921	14846	16304
	TIMBER C	9649	8956	4468	6223	5989	13463	9783
	TOTAL	43251	38921	25880	24832	32591	54924	53478
PRODUCT STORAGE (M3)	TIMBER A	0	0	174	0	0	0	0
	TIMBER C	0	0	223	0	0	0	0
	TOTAL	0	0	397	0	0	0	0

(PERIOD spans the columns 1988 to 2006-10.)

MILL TYPE CHIPSR

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		PERIOD 1990	1991-95
PRODUCT IMPORTS (M3)	CHIPS	500	19
	TOTAL	500	19
PRODUCTION (M3)	CHIPS	10000	386
	TOTAL	10000	386
PRODUCT STORAGE (M3)	CHIPS	500	0
	TOTAL	500	0

MILL TYPE MDFLR

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	CHIPS	2993	4500	0	4500	4500	5500	9000
	TOTAL	2993	4500	0	4500	4500	5500	9000
PRODUCTION (M3)	MDF	90000	90000	90000	90000	90000	110000	180000
	TOTAL	90000	90000	90000	90000	90000	110000	180000
PRODUCT STORAGE (M3)	CHIPS	0	728	13048	0	0	0	0
	MDF	0	0	4500	0	0	0	0
	TOTAL	0	728	17548	0	0	0	0

(PERIOD spans the columns 1988 to 2006-10.)

MILL TYPE OSBLR

TABLE 4. ANNUAL PROD'N, IMPORTS & STORAGE BY PRODUCT		1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	CHIPS	2098	4738	5000	5000
	TOTAL	2098	4738	5000	5000
PRODUCTION (M3)	OSB	41952	94757	100000	100000
	TOTAL	41952	94757	100000	100000

(PERIOD spans the columns 1991-95 to 2006-10.)

TOTAL, ALL MILLS

TABLE 4. ANNUAL IMPORTS, PROD'N & STORAGE		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRODUCT IMPORTS (M3)	CHIPS	2993	4500	500	6617	9238	10500	14000
	VENEER A	52	52	55	39	76	76	76
	TIMBER B	2647	2495	2619	2619	2619	3180	2017
	TOTAL	5692	7548	3174	9275	11933	13756	17048
PRODUC-TION (M3)	CHIPS	79807	73723	86984	78345	74923	90381	89589
	VENEER A	1048	1049	1098	1406	1522	1522	1522
	VENEER B	861	862	902	1155	1250	1250	1250
	TIMBER A	16902	15768	16631	16518	16003	14212	19301
	TIMBER B	52949	49908	52381	52381	52381	62855	74099
	TIMBER C	24000	24071	25263	32649	29892	42933	41600
	MDF	90000	90000	90000	90000	90000	110000	180000
	OSB	0	0	0	41952	94757	100000	100000
	TOTAL	265566	255383	273259	314405	360727	423153	507361
PRODUCT STORAGE (M3)	CHIPS	0	728	13548	0	0	0	0
	VENEER A	0	2	55	0	0	0	0
	VENEER B	0	0	45	0	0	0	0
	TIMBER A	0	0	832	0	0	0	0
	TIMBER B	1596	0	0	0	0	0	0
	TIMBER C	0	0	1263	0	0	0	0
	MDF	0	0	4500	0	0	0	0
	TOTAL	1596	729	20242	0	0	0	0

MILL TYPE SAWLC

TABLE 5. FINAL PRODUCT SALES		PERIOD						
PRODUCT	MARKET	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
TIMBER A	DOMESTIC	210	1799	0	973	1167	2795	0
	AUSTRALIA	3000	1390	0	4000	4000	0	0
	JAPAN/PACIF-IC	4902	3768	3188	3350	1803	0	3333
	ALL MARKETS	8112	6957	3188	8322	6970	2795	3333
TIMBER B	DOMESTIC	13377	10742	1331	5231	5958	4695	3939
	AUSTRALIA	14000	14000	15000	15000	15000	8000	7873
	ALL MARKETS	27377	24742	16331	20231	20958	12695	11812
TIMBER C	DOMESTIC	4512	10712	8634	6226	11177	418	0
	AUSTRALIA	0	0	2000	0	0	5000	3000
	JAPAN/PACIF-IC	0	71	0	6912	1892	4732	2417
	ALL MARKETS	4512	10783	10634	13138	13070	10150	5417
ALL PRODUCTS	DOMESTIC	18098	23253	9965	12429	18303	7908	3939
	AUSTRALIA	17000	15390	17000	19000	19000	13000	10874
	JAPAN/PACIF-IC	4902	3839	3188	10261	3695	4732	5750
	ALL MARKETS	40000	42482	30153	41691	40998	25640	20562

MILL TYPE SAWLR

TABLE 5. FINAL PRODUCT SALES PRODUCT	MARKET	1990	1991-95	1996-2000	2001-05	2006-10
TIMBER A	DOMESTIC	5703	6869	6667	6667	6287
	AUSTRALIA	1687	0	0	0	3713
	ALL MARKETS	7390	6869	6667	6667	10000
TIMBER B	DOMESTIC	27566	23462	23625	23625	32185
	AUSTRALIA	0	0	0	0	1565
	ALL MARKETS	27566	23462	23625	23625	33750
TIMBER C	DOMESTIC	5670	11474	10833	10833	15217
	JAPAN/PACIF-IC	0	0	0	0	1033
	ALL MARKETS	5670	11474	10833	10833	16250
ALL PRODUCTS	DOMESTIC	38938	41805	41125	41125	53689
	AUSTRALIA	1687	0	0	0	5278
	JAPAN/PACIF-IC	0	0	0	0	1033
	ALL MARKETS	40625	41805	41125	41125	60000

(PERIOD spans the year columns.)

MILL TYPE SAWSC

TABLE 5. FINAL PRODUCT SALES PRODUCT	MARKET	1988	1989	1990	1991-95	2001-05	2006-10
TIMBER A	DOMESTIC	6809	4323	0	1221	0	0
	AUSTRALIA	0	1610	1313	0	3058	1287
	JAPAN/PACIF-IC	0	0	612	0	0	768
	ALL MARKETS	6809	5933	1925	1221	3058	2055
TIMBER B	DOMESTIC	13792	19226	4139	4436	0	0
	AUSTRALIA	0	0	0	0	14127	13435
	ALL MARKETS	13792	19226	4139	4436	14127	13435
TIMBER C	DOMESTIC	7840	2332	3452	2854	287	0
	AUSTRALIA	2000	2000	0	0	0	5000
	JAPAN/PACIF-IC	0	0	0	0	8201	5150
	ALL MARKETS	9840	4332	3452	2854	8487	10150
ALL PRODUCTS	DOMESTIC	28440	25881	7591	8511	287	0
	AUSTRALIA	2000	3610	1313	0	17185	19722
	JAPAN/PACIF-IC	0	0	612	0	8201	5918
	ALL MARKETS	30440	29491	9516	8511	25673	25640

MILL TYPE SAWSR

TABLE 5. FINAL PRODUCT SALES		PERIOD						
PRODUCT	MARKET	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
TIMBER A	DOMESTIC	1981	2878	3297	937	2366	778	3913
	JAPAN/PACIFIC	0	0	0	0	0	953	0
	ALL MARKETS	1981	2878	3297	937	2366	1691	3913
TIMBER B	DOMESTIC	12832	10033	6965	6872	10417	15588	17120
	ALL MARKETS	12832	10033	6965	6872	10417	15588	17120
TIMBER C	DOMESTIC	9649	8956	4244	3446	2989	13463	9783
	AUSTRALIA	0	0	0	3000	3000	0	0
	ALL MARKETS	9649	8956	4244	6446	5989	13463	9783
ALL PRODUCTS	DOMESTIC	24462	21867	14506	11255	15772	29964	30815
	AUSTRALIA	0	0	0	3000	3000	0	0
	JAPAN/PACIFIC	0	0	0	0	0	953	0
	ALL MARKETS	24462	21867	14506	14255	18772	30742	30815

MILL TYPE VENSC

TABLE 5. FINAL PRODUCT SALES		PERIOD						
PRODUCT	MARKET	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
VENEER A	DOMESTIC	500	500	500	900	998	998	998
	AUSTRALIA	200	200	200	200	200	200	200
	JAPAN/PACIFIC	400	400	400	400	400	400	400
	ALL MARKETS	1100	1100	1100	1500	1598	1598	1598
VENEER B	DOMESTIC	400	400	400	450	500	500	500
	AUSTRALIA	100	200	200	250	250	250	250
	JAPAN/PACIFIC	361	262	257	500	500	500	500
	ALL MARKETS	861	862	857	1200	1250	1250	1250
ALL PRODUCTS	DOMESTIC	900	900	900	1350	1498	1498	1498
	AUSTRALIA	300	400	400	450	450	450	450
	JAPAN/PACIFIC	761	662	657	900	900	900	900
	ALL MARKETS	1961	1962	1957	2700	2848	2848	2848

MILL TYPE MDFLR

TABLE 5. FINAL PRODUCT SALES		PERIOD						
PRODUCT	MARKET	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
MDF	DOMESTIC	35000	35000	30500	39500	35000	50000	50000
	AUSTRALIA	15000	15000	15000	15000	15000	20000	20000
	JAPAN/PACIFIC	40000	40000	40000	40000	40000	40000	110000
	ALL MARKETS	90000	90000	85500	94500	90000	110000	180000

MILL TYPE OSBLR:

TABLE 5. FINAL PRODUCT SALES PRODUCT	MARKET	PERIOD 1991-95	1996-2000	2001-05	2006-10
OSB	DOMESTIC	16200	19500	19500	19500
	AUSTRALIA	15000	20000	20000	20000
	JAPAN/PACIF-IC	10752	55257	60500	60500
	ALL MARKETS	41952	94757	100000	100000

TOTAL, ALL MILLS

TABLE 5.FINAL PRODUCT SALES PRODUCT	MARKET	PERIOD 1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
VENEER A	DOMESTIC	500	500	500	900	998	998	998
	AUSTRALIA	200	200	200	200	200	200	200
	JAPAN/PACIF-IC	400	400	400	400	400	400	400
	ALL MARKETS	1100	1100	1100	1500	1598	1598	1598
VENEER B	DOMESTIC	400	400	400	450	500	500	500
	AUSTRALIA	100	200	200	250	250	250	250
	JAPAN/PACIF-IC	361	262	257	500	500	500	500
	ALL MARKETS	861	862	857	1200	1250	1250	1250
TIMBER A	DOMESTIC	9000	9000	9000	10000	10200	10200	10200
	AUSTRALIA	3000	3000	3000	4000	4000	3058	5000
	JAPAN/PACIF-IC	4902	3768	3800	3350	1803	953	4101
	ALL MARKETS	16902	15768	15800	17350	16003	14211	19301
TIMBER B	DOMESTIC	40000	40000	40000	40000	40000	43908	53244
	AUSTRALIA	14000	14000	15000	15000	15000	22127	22873
	ALL MARKETS	54000	54000	55000	55000	55000	66035	76116
TIMBER C	DOMESTIC	22000	22000	22000	24000	25000	25000	25000
	AUSTRALIA	2000	2000	2000	3000	3000	5000	8000
	JAPAN/PACIF-IC	0	71	0	6912	1892	12933	8600
	ALL MARKETS	24000	24071	24000	33912	29892	42933	41600
MDF	DOMESTIC	35000	35000	30500	39500	35000	50000	50000
	AUSTRALIA	15000	15000	15000	15000	15000	20000	20000
	JAPAN/PACIF-IC	40000	40000	40000	40000	40000	40000	110000
	ALL MARKETS	90000	90000	85500	94500	90000	110000	180000
OSB	DOMESTIC	0	0	0	16200	19500	19500	19500
	AUSTRALIA	0	0	0	15000	20000	20000	20000
	JAPAN/PACIF-IC	0	0	0	10752	55257	60500	60500
	ALL MARKETS	0	0	0	41952	94757	100000	100000
ALL PRODUCTS	DOMESTIC	106900	106900	102400	131050	131198	150106	159442
	AUSTRALIA	34300	34400	35400	52450	57450	70635	76323
	JAPAN/PACIF-IC	45663	44501	44457	61914	99852	115286	184101
	ALL MARKETS	186863	185801	182257	245414	288500	336027	419866

TABLE 6. CAPACITY CHANGES MILL TYPE	NUMBER OF:	PERIOD 1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
SAWLC	SHUT-DOWNS	0	0	0	0	0	0	1
SAWLR	START-UPS	0	1	0	0	0	0	1
SAWSC	SHUT-DOWNS	1	0	1	0	0	0	0
SAWSR	SHUT-DOWNS	0	2	1	0	0	0	0
VENSC	START-UPS	0	0	0	1	0	0	0
CHIPSR	SHUT-DOWNS	0	0	0	0	0	1	0
MDFLR	START-UPS	0	0	0	0	0	1	0
OSBLR	START-UPS	0	0	0	1	0	0	0

LOG TYPE PRUNED

TABLE 7. LOCAL LOG SUPPLIES BY FOREST (M3)		PERIOD 1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PLAINS	AVAILABLE	19500	13800	13900	12800	29100	48400	58400
	PURCHASED	19500	13800	13900	12800	16923	5435	5435
	SH.PRICE	222	207	221	42	0	0	0
FOOTHIL-LS	AVAILABLE	4800	6200	8000	9800	20800	28500	33400
	PURCHASED	4800	6200	8000	9800	0	0	0
	SH.PRICE	217	207	221	21	0	0	0

LOG TYPE UNPRUNED

TABLE 7. LOCAL LOG SUPPLIES BY FOREST (M3)		PERIOD 1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PLAINS	AVAILABLE	19000	13000	12900	15200	30500	49300	63600
	PURCHASED	19000	13000	12900	15200	30500	49300	23105
	SH.PRICE	402	404	411	186	107	9	0
FOOTHIL-LS	AVAILABLE	4600	5800	7300	11900	23300	29200	37200
	PURCHASED	4600	5800	7300	11900	23300	29200	0
	SH.PRICE	397	399	375	196	98	17	0
PRIVATE	AVAILABLE	121800	117200	115300	90800	99300	132800	214400
	PURCHASED	121800	117200	115300	90800	99300	113690	211884
	SH.PRICE	399	401	377	204	105	0	0

LOG TYPE OTHER

TABLE 7. LOCAL LOG SUPPLIES BY FOREST (M3)		PERIOD 1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PLAINS	AVAILABLE	10900	11500	13400	15000	29600	44600	50600
	PURCHASED	10900	11500	13400	15000	29600	44600	50600
	SH.PRICE	350	336	327	235	130	31	24
FOOTHIL-LS	AVAILABLE	2700	5800	7300	12200	22800	26400	29400
	PURCHASED	2700	5800	7300	12200	22800	26400	29400
	SH.PRICE	345	336	343	215	128	39	31
PRIVATE	AVAILABLE	23600	26700	26700	22400	28000	35800	56200
	PURCHASED	23600	26700	26700	22400	28000	35800	56200
	SH.PRICE	347	338	345	223	134	44	35

LOG TYPE RESIDUAL

TABLE 7. LOCAL LOG SUPPLIES BY FOREST (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PLAINS	AVAILABLE	25900	46200	35600	40200	65800	88900	103200
	PURCHASED	25900	25770	35600	40200	65800	88900	103200
	SH.PRICE	23	0	28	212	185	85	68
FOOTHIL-LS	AVAILABLE	6300	20800	21400	33100	51400	52800	59900
	PURCHASED	6300	20800	21400	33100	51400	52800	59900
	SH.PRICE	26	3	31	225	195	93	74
PRIVATE	AVAILABLE	45800	49300	52000	45100	52100	67800	110000
	PURCHASED	45800	49300	52000	45100	52100	67800	110000
	SH.PRICE	28	5	33	233	202	98	79

TOTAL, ALL LOG TYPES

TABLE 7. LOCAL LOG SUPPLIES BY FOREST (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PLAINS	AVAILABLE	75300	84500	75800	83200	155000	231200	275800
	PURCHASED	75300	64070	75800	83200	142823	188235	182339
FOOTHIL-LS	AVAILABLE	18400	38600	44000	67000	118300	136900	159900
	PURCHASED	18400	38600	44000	67000	97500	108400	89300
PRIVATE	AVAILABLE	191200	193200	194000	158300	179400	236400	380600
	PURCHASED	191200	193200	194000	158300	179400	217290	378084
TOTAL	AVAILABLE	267900	295870	313800	308500	452700	604500	816300
	PURCHASED	267900	295870	313800	308500	419723	513925	649723

TABLE 8. LOG IMPORT SUPPLIES BY TYPE (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
PRUNED	AVAILABLE	5000	5000	5000	7500	10000	10000	12500
	IMPORTED	5000	5000	5000	370	0	0	0
	SH.PRICE	212	200	203	0	0	0	0
UNPRUNED	AVAILABLE	7500	7500	7500	10000	12500	12500	15000
	IMPORTED	7500	7500	7500	10000	12500	0	0
	SH.PRICE	394	396	404	183	80	0	0
OTHER	AVAILABLE	5000	5000	5000	7500	10000	10000	12500
	IMPORTED	5000	5000	5000	7500	10000	10000	12500
	SH.PRICE	341	332	341	206	111	26	20
RESIDUAL	AVAILABLE	7500	7500	7500	10000	12500	12500	15000
	IMPORTED	7500	0	7500	10000	12500	12500	15000
	SH.PRICE	22	0	6	208	182	82	66
TOTAL	AVAILABLE	25000	25000	25000	35000	45000	45000	55000
	IMPORTED	25000	17500	25000	27870	35000	22500	27500

TABLE 9. EMPLOYMENT LEVELS (MAN-YEARS)	PERIOD						
	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
REQUIRED	350	350	350	350	300	300	300
GENERATED	388	359	367	447	529	636	720
SH.PRICE	0	0	0	0	0	0	0

TABLE 10. WATER USAGE (MM 1)	PERIOD						
	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
AVAILABLE	200000	200000	200000	200000	200000	200000	200000
USED	59533	60714	64165	90563	121618	134109	162109
SH.PRICE	0	0	0	0	0	0	0

TABLE 11. CAPITAL USAGE (MM $ NZ)	PERIOD						
	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
AVAILABLE	50	75	100	125	150	150	150
USED	0	13.25	0	75	0	55	8.75
SH.PRICE	0	0	0	0	0	0	0

PRODUCT: VENEER A

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	800	800	800	900	1000	1000	1000
	LOWERBD.	500	500	500	500	500	500	500
	SALES	500	500	500	900	998	998	998
	SH.PRICE	0	0	0	370	0	0	0
AUSTRALIA	UPPERBD.	400	400	400	500	500	500	500
	LOWERBD.	200	200	200	200	200	200	200
	SALES	200	200	200	200	200	200	200
	SH.PRICE	0	0	0	0	0	0	0
JAPAN/PACI-FIC	UPPERBD.	1000	1000	1000	1000	1000	1000	1000
	LOWERBD.	400	400	400	400	400	400	400
	SALES	400	400	400	400	400	400	400
	SH.PRICE	0	0	0	0	0	0	0
ALL MARKETS	UPPERBD.	2200	2200	2200	2400	2500	2500	2500
	LOWERBD.	1100	1100	1100	1100	1100	1100	1100
	SALES	1100	1100	1100	1500	1598	1598	1598

PRODUCT: VENEER B

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	400	400	400	450	500	500	500
	LOWERBD.	250	250	250	250	250	250	250
	SALES	400	400	400	450	500	500	500
	SH.PRICE	98	92	86	70	14	49	47
AUSTRALIA	UPPERBD.	200	200	200	250	250	250	250
	LOWERBD.	100	100	100	100	100	100	100
	SALES	100	200	200	250	250	250	250
	SH.PRICE	47	44	41	86	95	64	87
JAPAN/PACI-FIC	UPPERBD.	500	500	500	500	500	500	500
	LOWERBD.	200	200	200	200	200	200	200
	SALES	361	262	257	500	500	500	500
	SH.PRICE	0	0	0	18	75	79	26
ALL MARKETS	UPPERBD.	1100	1100	1100	1200	1250	1250	1250
	LOWERBD.	550	550	550	550	550	550	550
	SALES	861	862	857	1200	1250	1250	1250

PRODUCT: TIMBER A

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	9000	9000	9000	10000	10200	10200	10200
	LOWERBD.	6000	6000	6000	6000	6000	6000	6000
	SALES	9000	9000	9000	10000	10200	10200	10200
	SH.PRICE	128	120	116	459	303	3	148
AUSTRALIA	UPPERBD.	3000	3000	3000	4000	4000	5000	5000
	LOWERBD.	2500	2500	2500	2500	2500	2500	2500
	SALES	3000	3000	3000	4000	4000	3058	5000
	SH.PRICE	121	114	106	435	298	0	140
JAPAN/PACI-FIC	UPPERBD.	5000	5000	5000	9000	9000	15000	15000
	LOWERBD.	0	0	0	0	0	0	0
	SALES	4902	3768	3800	3350	1803	953	4101
	SH.PRICE	0	0	0	0	0	0	0
ALL MARKETS	UPPERBD.	17000	17000	17000	23000	23200	30200	30200
	LOWERBD.	8500	8500	8500	8500	8500	8500	8500
	SALES	16902	15768	15800	17350	16003	14211	19301

PRODUCT: TIMBER B

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	55000	55000	55000	60000	62000	62000	62000
	LOWERBD.	40000	40000	40000	40000	40000	40000	40000
	SALES	40000	40000	40000	40000	40000	43908	53244
	SH.PRICE	4	4	3	4	7	0	0
AUSTRALIA	UPPERBD.	16000	16000	16000	20000	25000	32000	32000
	LOWERBD.	14000	14000	15000	15000	15000	15000	15000
	SALES	14000	14000	15000	15000	15000	22127	22873
	SH.PRICE	5	4	8	7	2	0	0
ALL MARKETS	UPPERBD.	76000	76000	76000	95000	112000	129000	129000
	LOWERBD.	54000	54000	55000	55000	55000	55000	55000
	SALES	54000	54000	55000	55000	55000	66035	76116

PRODUCT: TIMBER C

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	22000	22000	22000	24000	25000	25000	25000
	LOWERBD.	16000	16000	16000	16000	16000	16000	16000
	SALES	22000	22000	22000	24000	25000	25000	25000
	SH.PRICE	18	24	22	90	64	46	39
AUSTRALIA	UPPERBD.	2000	2000	2000	3000	3000	8000	8000
	LOWERBD.	500	500	500	500	500	500	500
	SALES	2000	2000	2000	3000	3000	5000	8000
	SH.PRICE	12	17	16	50	36	0	20
JAPAN/PACI-FIC	UPPERBD.	5000	5000	5000	7500	7500	15000	15000
	LOWERBD.	0	0	0	0	0	0	0
	SALES	0	71	0	6912	1892	12933	8600
	SH.PRICE	0	0	0	0	0	0	0
ALL MARKETS	UPPERBD.	29000	29000	29000	34500	35500	48000	48000
	LOWERBD.	16500	16500	16500	16500	16500	16500	16500
	SALES	24000	24071	24000	33912	29892	42933	41600

PRODUCT: MDF

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	35000	35000	40000	40000	50000	50000	50000
	LOWERBD.	20000	20000	20000	20000	20000	20000	20000
	SALES	35000	35000	30500	39500	35000	50000	50000
	SH.PRICE	180	124	122	90	64	46	39
AUSTRALIA	UPPERBD.	25000	25000	25000	20000	20000	20000	20000
	LOWERBD.	15000	15000	15000	15000	15000	15000	15000
	SALES	15000	15000	15000	15000	15000	20000	20000
	SH.PRICE	0	0	0	0	0	34	24
JAPAN/PACI-FIC	UPPERBD.	60000	60000	70000	80000	110000	110000	110000
	LOWERBD.	40000	40000	40000	40000	40000	40000	40000
	SALES	40000	40000	40000	40000	40000	40000	110000
	SH.PRICE	0	0	0	0	0	0	20
ALL MARKETS	UPPERBD.	120000	120000	135000	140000	180000	180000	180000
	LOWERBD.	75000	75000	75000	75000	75000	75000	75000
	SALES	90000	90000	85500	94500	90000	110000	180000

PRODUCT: OSB

TABLE 12. MARKET LIMITS AND SALES (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
DOMESTIC	UPPERBD.	15000	15000	16200	16200	19500	19500	19500
	LOWERBD.	0	0	0	0	0	0	0
	SALES	0	0	0	16200	19500	19500	19500
	SH.PRICE	0	0	0	90	64	46	39
AUSTRALIA	UPPERBD.	5000	7500	10000	20000	20000	20000	20000
	LOWERBD.	0	0	0	0	0	0	0
	SALES	0	0	0	15000	20000	20000	20000
	SH.PRICE	0	0	0	0	36	34	24
JAPAN/PACI-FIC	UPPERBD.	15000	25000	35000	45000	60500	60500	60500
	LOWERBD.	0	0	0	0	0	0	0
	SALES	0	0	0	10752	55257	60500	60500
	SH.PRICE	0	0	0	0	0	20	18
ALL MARKETS	UPPERBD.	35000	47500	61200	81200	100000	100000	100000
	LOWERBD.	0	0	0	0	0	0	0
	SALES	0	0	0	41952	94757	100000	100000

TABLE 13. PORT CAPACITIES AND THROUGHPUTS (M3)		PERIOD						
		1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
COMMODITY								
EXPORT CHIPS	CAPACITY	360000	360000	360000	420000	800000	860000	940000
	THRU-PUT	0	0	0	0	0	0	0
	SH.PRICE	0	0	0	0	0	0	0
PANELS	CAPACITY	400000	400000	400000	440000	700000	740000	800000
	THRU-PUT	56061	56062	56057	82102	131607	141850	211850
	SH.PRICE	0	0	0	0	0	0	0
SAWNTIMBER	CAPACITY	60000	60000	60000	100000	180000	240000	280000
	THRU-PUT	23902	22839	23800	32261	25695	47750	38951
	SH.PRICE	0	0	0	0	0	0	0
TOTAL	CAPACITY	820000	820000	820000	960000	1680000	1840000	2020000
	THRU-PUT	79963	78901	79857	114364	157302	174600	243801

TABLE 14. CAPACITY UTILISATION (%)		PERIOD						
MILLTYPE	CAPACITY	1988	1989	1990	1991-95	1996-2000	2001-05	2006-10
SAWLC	EXISTING(M3)	40000	40000	40000	40000	40000	40000	20000
	PROD'N (M3)	40000	40000	30103	40000	40000	25000	20000
	UTILISED (%)	100	100	75	100	100	63	100
SAWLR	EXISTING(M3)	0	0	40000	40000	40000	40000	60000
	PROD'N (M3)	0	0	40000	40000	40000	40000	60000
	UTILISED (%)	na	na	100	100	100	100	100
SAWSC	EXISTING(M3)	30000	30000	25000	25000	25000	25000	25000
	PROD'N (M3)	30000	28358	9600	8017	8358	25000	25000
	UTILISED (%)	100	94	38	32	33	100	100
SAWSR	EXISTING(M3)	45000	35000	30000	30000	30000	30000	30000
	PROD'N (M3)	23850	21390	14572	13531	18276	30000	30000
	UTILISED (%)	53	61	49	45	61	100	100
VENSC	EXISTING(M3)	2000	2000	2000	4000	4000	4000	4000
	PROD'N (M3)	1909	1911	2000	2561	2772	2772	2772
	UTILISED (%)	95	96	100	64	69	69	69
CHIPSR	EXISTING(M3)	10000	10000	10000	10000	10000	0	0
	PROD'N (M3)	0	0	10000	386	0	0	0
	UTILISED (%)	0	0	100	4	0	na	na
MDFLR	EXISTING(M3)	90000	90000	90000	90000	90000	180000	180000
	PROD'N (M3)	90000	90000	90000	90000	90000	110000	180000
	UTILISED (%)	100	100	100	100	100	61	100
OSBLR	EXISTING(M3)	0	0	0	100000	100000	100000	100000
	PROD'N (M3)	0	0	0	41952	94757	100000	100000
	UTILISED (%)	na	na	na	42	95	100	100

APPENDIX B

SAWMILL STUDY AND SURVEY FORM

This appendix contains copies of the report on the Canterbury sawmilling industry and the associated survey form referred to in the text.

THE SAWMILLING INDUSTRY IN CANTERBURY

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April 1987

INTRODUCTION

The purpose of this report is to provide detailed statistics on the prime users of Canterbury's industrial timber resource, the sawmilling industry. The need for such information arose from a study, currently underway at the University of Canterbury, which has the broad aim of constructing a regional strategic planning model for wood processors. The specific objectives of this study are :

(i) to produce a methodology for coordinating such factors as forest resources, forecasted market demands for forest produce, existing (and potential) processing capability and productivity, and infrastructural consequences, while emphasizing processing;

(ii) to deal specifically with processing options for the Canterbury region (as defined by the Department of Statistics), while serving as a prototype applicable to any region of New Zealand.

Attainment of these objectives will result in an aggregated processing model which is coordinated and compatible with existing forest and market models.

The main aim of the data collection summarized here was to provide accurate information for testing the modelling methodology outlined above. This report will be circulated amongst the sawmillers who provided the data, for feedback and, if necessary, revision.

BACKGROUND

The Canterbury region, extending from the Rakaia River in the south to the Conway River in the north and bounded by the Main Divide to the west (see Figure 1), has not been well endowed with forests for many years. Early settlers found roughly half of the region under forest cover, most of this in or near the foothills and Banks Peninsula. This was not truly indicative of the timber potential of the area, however, as it is widely held that Maori land clearing and cultivation on the Canterbury Plains caused the destruction of much of this area's primitive forests (Poole and Adams 1980). The arrival of the first Europeans heralded a new age in forest exploitation, with Canterbury's first sawmills established on Banks Peninsula to provide timber for early settlements.

Most of these early sawmills were fairly shortlived, lasting only so long as readily available supplies of wood were at hand. The rapid depletion of Canterbury's indigenous resource, due to the twin pressures of settlement and fire, led to the first early plantings of exotic species. Hanmer State Forest was the first such effort in 1902, closely followed by the Selwyn Plantation Board's first plantings to provide for both shelter and timber needs on the plains.

Canterbury's current area of net productive exotic stocked forest of 47 621 ha (about 5 percent of the national total) is split 3:2 between the Forestry Corporation and private owners (Table 1). Documentation of the 18 396 ha private resource is poor in comparison to that of State owned forests, with private owners encompassing farmers, other individuals, informal groups and local authorities. Figure 2 shows

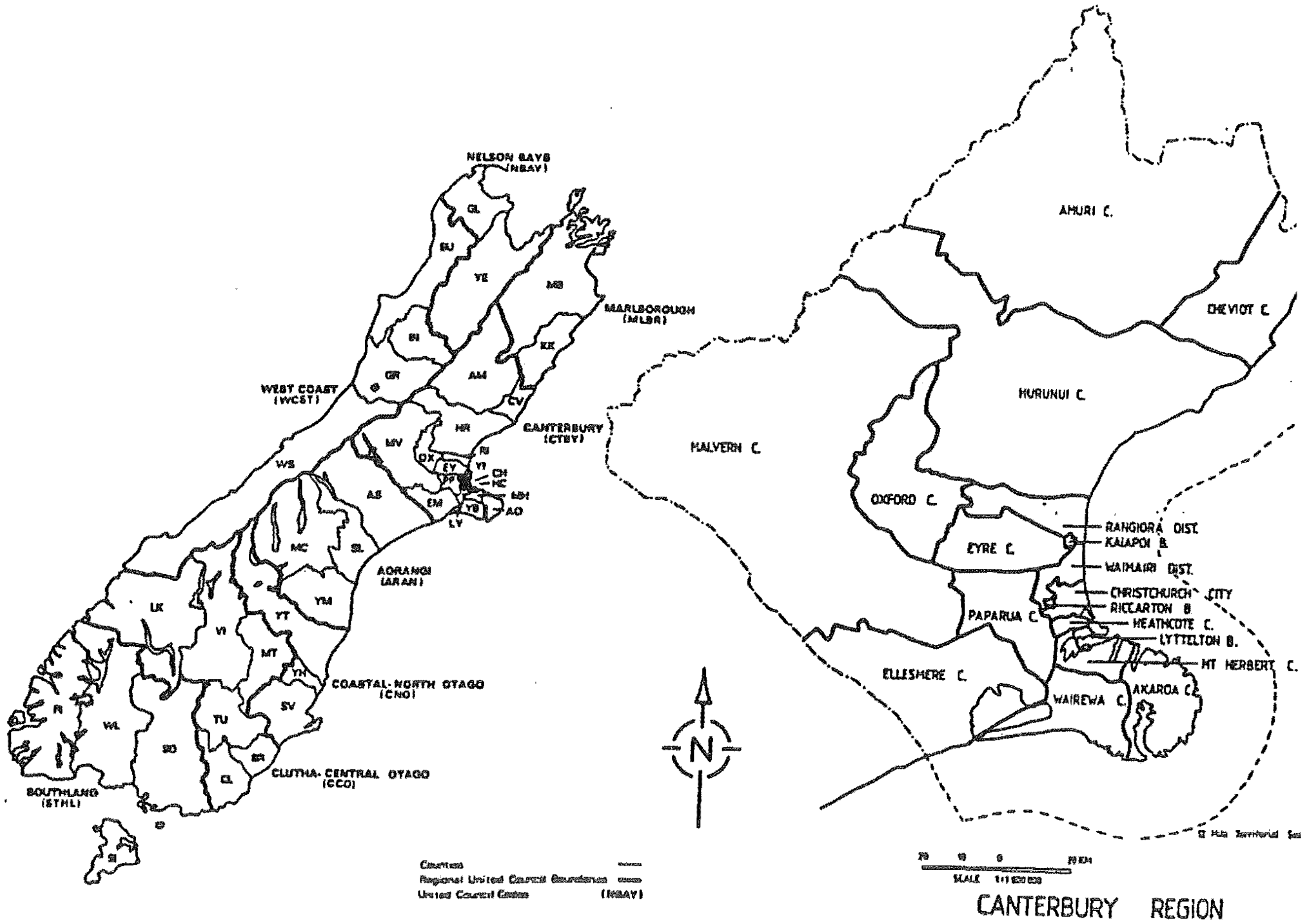

Figure 1. The Canterbury region (with county boundaries)

the species breakdown: 83 percent of the region's exotic forest area (39 191 ha) is planted in radiata pine, with the remainder consisting of Douglas-fir (8 percent), other exotic softwoods (8 percent) and exotic hardwoods (1 percent). The volume of growing stock in these forests is estimated at 7 645 000 m³ with a current annual increment of 626 000 m³ per year (Burrows et al. 1987).

Table 1. Canterbury exotic forest area ownership (1 April 1986)

Owner	State	Private	Total
ha	29 225 (61%)	18 396 (39%)	47 621

Source: Burrows et al. 1987.

Indigenous forests, consisting primarily of Nothofagus species, cover 220 000 ha of Canterbury. These forests are concentrated on the foothills and slopes of the Southern Alps and are largely unmerchantable, due to their protection and/or recreational status. With annual production from indigenous forests spiralling ever downward (less than 1500 m³ in 1984 - NZFS 1985) it appears that the bulk of industrial timber produced in Canterbury will continue to come from private and State owned exotic forests.

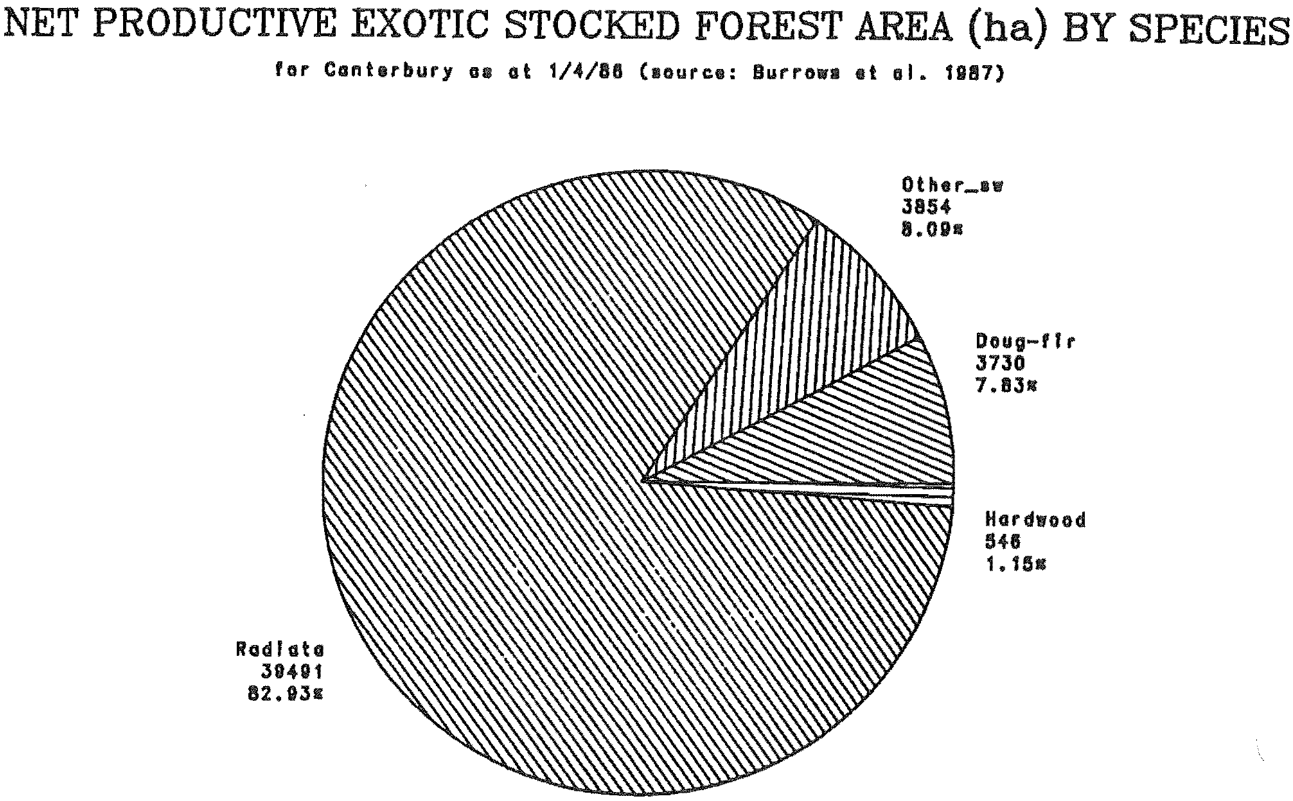

Figure 2. Species distribution in Canterbury's exotic forests.

RATIONALE

The current area weighted average age of Canterbury's exotic forests is 13 years, with less than 8 percent of the exotic forest area holding stands older than 30 years (Burrows et al. 1987). Figure 3 illustrates the imbalance in the age class structure of the region's forests. This imbalance has already caused timber shortages which are likely to increase in severity over the next decade. Sawlog prices are predicted to rise (Levy 1986) as farmers and other holders of mature timber realize that demand for their wood exceeds the supply.

Table 2 shows the change in the number of sawmills operating in Canterbury over the past five years. The downward trend portrayed in this table can be explained, at least partially, by Canterbury's rising wood costs, already amongst the highest in New Zealand (Hawkins, pers. comm. 1986).

For Canterbury to realise the benefits of the increase in wood supplies expected in the next 20 years (see Figure 3), additional milling capacity must be in place by the turn of the century. With sawlog production expected to increase by a factor of four in State (Forestry Corporation) Forests alone (from just over 70 000 m^3 per year to over 300 000 m^3 per year by 2010 - NZFS 1985), the potential for an expanded industry is considerable.

The proposed necessity for increases in processing capacity to accompany increases in wood supply raises several difficult questions for sawmillers and regional planners/policy makers. Should processing capacity be increased? If so, when? How should the required capital be raised? If processing capacity is not increased to keep pace with wood

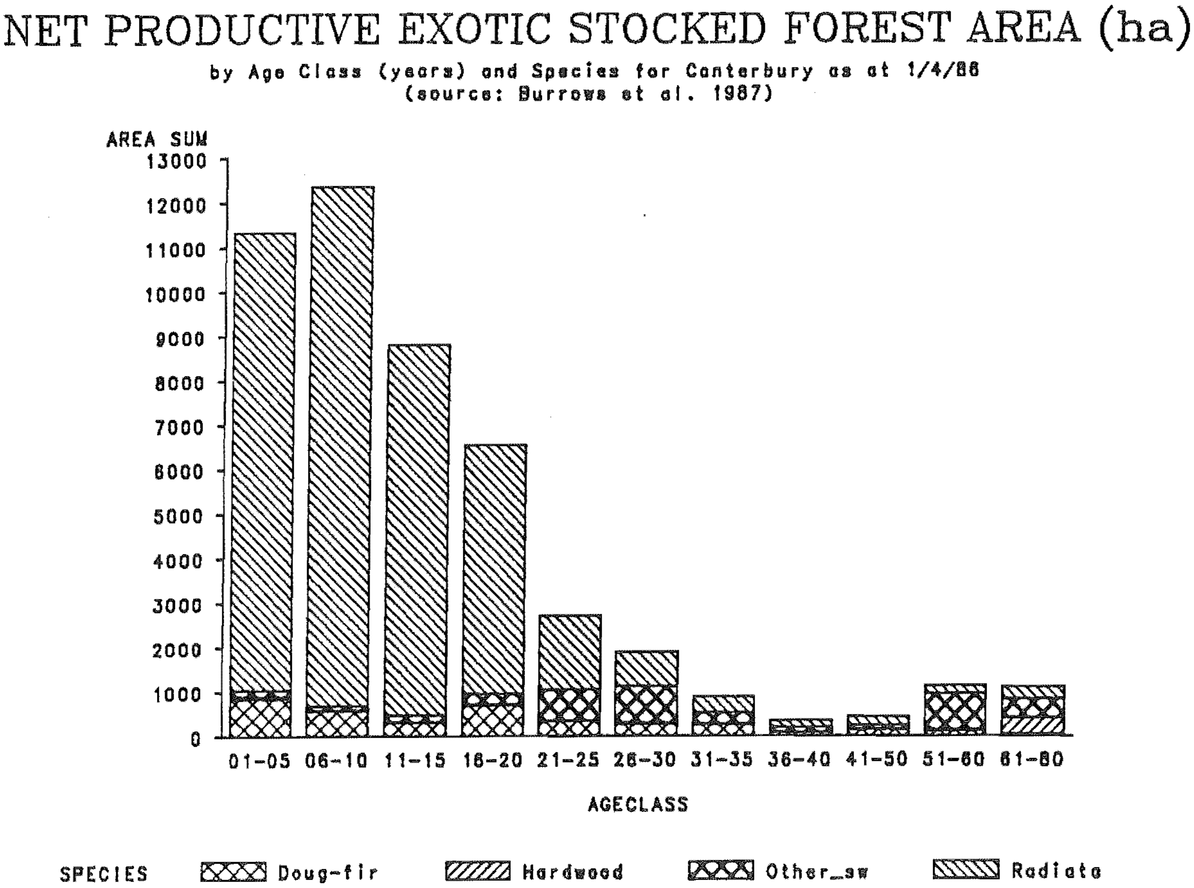

Figure 3. Age class distribution in Canterbury's exotic forests.

Table 2. Number of sawmills operating in Canterbury

Year :	1982	1984	1986
Number:	34	28	21

Sources : Department of Statistics 1982
: Department of Statistics 1984
: Survey of mills (includes one mill selling but not producing)

supplies, are there export markets or other regions willing to buy Canterbury's surplus logs? Should increases in processing capacity be encouraged in sawmilling alone? Or in other processing options (i.e. reconstituted board production) as well? Finally, what market(s) will any such increases in production be aimed at? These questions, and many more like them, must ultimately be dealt with in the boardroom and/or the political arena. The need for quantitative information to aid this type of decision-making analysis would appear to be undeniable.

The New Zealand Forest Service publishes annual collections of forest and forest industry statistics (e.g.,NZFS 1986). Additional information can be obtained from the biennial Census of Manufacturing (e.g.,Department of Statistics 1982, 1984), the New Zealand Official Yearbook (e.g.,Department of Statistics 1985) and the annual report of the Director-General of Forests (e.g.,Kirkland 1986). Although valuable, much of this information is highly aggregated and does not fully meet the needs of decision-makers faced with the type of questions posed above. The data presented in this report represent an initial attempt to collect more detailed statistics on the Canterbury sawmill industry than those released officially in these publications.

DATA COLLECTION

Detailed questionnaires (copies available on request) were sent to Canterbury sawmillers in mid 1986, designed to collect information supplementary to that published by the Forest Service and Department of Statistics. Twenty of the twenty-one sawmills in the region were visited within two months of this mailing for a follow up interview. Addresses and phone numbers of interviewees were obtained from Forest Service sawmill registrations and from the membership list of the Canterbury Timber Association.

While most mill managers were happy to be visited, the level of cooperation in providing the relevant data varied markedly. Although every effort was made to ensure consistent, accurate responses this was not always possible. Despite these shortcomings, this data set provides a clearer picture of the Canterbury sawmill industry than hitherto available.

DATA TABLES AND DISCUSSION

1. General

Table 3 breaks down the Canterbury sawmill industry by production level (four classes) and by geographical area (county codes taken from Figure 1). The majority of the region's mills (eleven, or 53 percent) are located within 30km of Christchurch, reflecting a greater desire to be near final product and labour markets than wood supplies. These 11 mills produce 70 percent of the region's sawn timber.

The variability of the sawmill industry is marked, with annual outputs of sawn timber ranging from 500 to 24 000 m^3 (Table 4). Although there are more small mills, production is largely concentrated in the larger size classes, with the top two mills (9 percent of all mills) producing more than a third of total output (Table 5).

Despite their relatively minor contribution to total output, Canterbury's smaller sawmills are important in local economies. An examination of Table 3 and Figure 1 shows that most of these mills are in counties some distance from Christchurch. Many are in rural locations, providing an important source of income for owners and employees, while utilising isolated tracts of timber (often farm woodlots) to provide low cost timber to these rural economies. Unfortunately, it is primarily this type of mill which is most susceptible to rising costs, contributing disproportionately to the trend illustrated in Table 2.

All of Canterbury's sawmills are privately owned, most being family businesses or partnerships. The average length of current ownership is 15 years, indicating a relatively stable industry. However, of the 14 mills which were identified as being owned or operated by a family interest, 7 indicated that it was unlikely that mill ownership would continue in the family for another generation.

Only one portable sawmiller was surveyed; although costs and revenues for such operations (involved for the most part in custom sawing) are not strictly comparable to those of stationary sawmills, the

Table 3. Number of mills by production class (m^3) and county.

Class/Cty	AM	AO	CV	EM	EY	HC	HR	MH	MV	OX	PP	RI	YB	YI	Total
>10 000	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
5 001-10 000	0	0	0	0	0	0	0	0	1	0	1	0	0	3	5
2 500- 5 000	0	0	0	0	0	2	0	0	1	1	1	0	0	1	6
< 2 500	1	1	0	0	0	1	1	1	0	1	0	2	0	0	8
Total	1	1	0	0	0	3	1	1	2	2	2	3	0	5	21

Note: county codes from Figure 1; Heathcote Cty (HC) incorporates ChCh south, Mt. Herbert Cty (MH) incorporates Lyttleton Borough, Rangiora District (RI) incorporates Kaiapoi Borough, Waimari District incorporates Riccarton Borough and ChCh north.

Table 4. Annual sawn timber output (m^3) by production class.

Class/Statistic	Class Mean	Class Min.	Class Max.	Class Total
>10 000	17 250.0	10 500.0	24 000.0	34 500.0
5 001-10 000	7 032.2	5 184.0	9 127.0	35 161.0
2 500- 5 000	3 759.8	3 000.0	4 859.0	22 559.0
< 2 500	1 227.6	500.0	2 400.0	9 821.0
Total	4 859.1	500.0	24 000.0	102 041.0

Table 5. Concentration of production.

Cumulative no. of mills	Cumulative % of mills	Cumulative % of prod'n
2	9.5	33.5
4	19.0	50.2
7	33.3	68.1
11	52.4	84.4
16	76.2	96.2
21	100.0	100.0

data are included here for completeness. Finally, only mills producing sawn timber as an end product are included in this analysis; thus Canterbury's two chipmills are not considered here.

2. Production.

Table 6 shows the distribution of lumber processing equipment in Canterbury sawmills as well as the number of mills planning to introduce new or upgraded equipment within the next year and the resulting totals. The main types of additions planned (debarker, bandsaw, band resaw, edger/trimmer, chipper) will contribute to increased conversion efficiency, and possibly to increased production in the recipient mills. The planned introduction of 4 chippers will further erode firewood production in the region, exacerbating existing firewood shortages (Jamieson 1986).

Total log volumes used by each production class are broken down in Table 7 into sawn timber, firewood and chip volumes produced. The two largest mills produced 69 percent of all wood chips, while the 14 mills in the lower two production classes produced 65 percent of all firewood. This is due largely to the lack of debarking equipment in smaller mills, as wood chips must be sold relatively bark free.

An average conversion factor is also shown for each class in Table 7. Conversion factor is defined as nominal sawn timber volume output divided by log volume input and is one measure of a mill's processing efficiency. Other measures of efficiency, such as speed of manufacture and grade recovery, are also important. However, with further increases in wood prices imminent, the percentage of total manufacturing costs attributable to raw materials is likely to rise above the present level of 40 percent (Table 12), already considered excessive. As such, the importance of getting the most out of these raw materials (conversion efficiency) cannot be overstated.

Table 7 presents a conversion factor for all species/grades as information on sawntimber production broken down by these variables was seldom available. As has been found in a recent North American study (Steele and Risbrudt 1986), conversion factor tends to decrease with decreasing mill size, reflecting the generally lower level of sophistication and lower speed of throughput in smaller mills. The relatively high average conversion factor observed in the second largest production class (5 000 - 10 000m^3) is largely due to the presence in this class of a mill whose primary product is pallets. The box grades required for this product are recovered quite efficiently in the mill, which has a conversion factor of 63 percent. The average conversion factor for this class drops from 52 to 49 percent when the pallet mill is omitted from the analysis.

Operating ratio is the ratio of normal output to engineered capacity per 8-hour shift (Bannock et al. 1978). Operating ratios less than one reflect under-utilised capacity, while a value of one indicates that any production increase requires an increase in capital expenditure and/or the number of shifts worked. Output, capacity and operating ratio are summarised for each production class in Table 8. As all mills worked single shifts, average operating ratios were derived from annual (versus per shift) output/capacity figures. Canterbury's sawmilling capacity is currently under-utilised by about 20 percent, with some of the smaller mills operating at half their rated capacity. This is due largely to wood shortages (most of these mills do not have contracts with the Forest Service for their wood) and to recent disturbances in export markets (chiefly Australia) caused by the floating New Zealand dollar.

Sawntimber production for the industry as a whole is broken down into grades and species in Tables 9 and 10, respectively. Table 10 was derived by multiplying the log volumes for each species by the mill's conversion factor, as many mills do not break down output by species. It is worth noting that framing grades constitute 61 percent of Canterbury's sawn timber output, with "clear" grades (factory, finishing and dressing) making up only 6 percent in total. As 40 percent of Canterbury's exotic forest area is currently being intensively tended to produce pruned butt logs greater than 5 metres long (p.70, Burrows et al. 1987), millers will have to adapt sawing methods and seek out new markets in order to take advantage of this clearwood resource. The nature of this new resource will also have implications for log grading and bucking practices in the woods - millers will need to ensure that they are receiving the log mix required to service their markets.

Table 6. Processing equipment distribution and planned additions.

Equipment No. (%) of mills:	Current	Planned	Total
Debarker	7 (33.3)	3 (14.3)	10 (47.6)
Circular saw	12 (57.1)	0 (0.0)	12 (57.1)
Band saw	9 (42.9)	2 (9.5)	11 (52.4)
Breast bench	17 (80.9)	0 (0.0)	17 (80.9)
Band resaw/reman	5 (23.8)	4 (19.0)	9 (42.8)
Gang edger/trimmer	6 (28.6)	1 (4.8)	7 (33.4)
Docking saw	19 (90.5)	0 (0.0)	19 (90.5)
Chipper	7 (33.3)	4 (19.0)	11 (52.4)
Planer/4-sider	11 (52.4)	0 (0.0)	11 (52.4)
Kiln	4 (19.0)	0 (0.0)	4 (19.0)
Treatment plant	7 (33.3)	0 (0.0)	7 (33.3)

Table 7. Log and production volumes (m³) with average conversion factors

Class/Item	Logs	Sawn timber	Firewood	Chips	Avg C.F. (Range)
>10 000	70 800	34 500	0	22 000	0.49 (0.48-0.49)
5 001-10 000	68 255	35 161	8 200	6 241	0.52 (0.49-0.63)
2 500- 5 000	48 211	22 559	11 600	1 938	0.47 (0.43-0.49)
< 2 500	21 800	9 821	3 600	1 800	0.44 (0.40-0.48)
Total	209 066	102 041	23 400	31 979	0.47 (0.40-0.63)

Table 8. Normal output, engineered capacity and average operating ratios

Class/Item	Output (m³)	Capacity (m³)	Avg O.R. (Range)
>10 000	34 500	40 000	0.83 (0.70-0.96)
5 001-10 000	35 161	36 600	0.96 (0.91-1.00)
2 500- 5 000	22 559	29 800	0.76 (0.57-0.96)
< 2 500	9 821	12 800	0.76 (0.50-1.00)
Total	102 041	119 200	0.82 (0.50-1.00)

Table 9. Sawntimber production by grade (all species).

Grade	Production (m³)	Production (%)
Factory	2 749.9	2.7
Finishing	1 010.0	1.0
Dressing	2 690.7	2.6
Merchantable	9 402.6	9.2
Framing	61 918.3	60.7
Box	17 047.2	16.7
Other	7 222.3	7.1
Total	102 041.0	100.0

Note: "Other" includes pallets, posts, poles, etc.

Table 10. Sawntimber production by species (all grades).

Species	Production (m³)	Production (%)
Radiata	80 734.3	79.1
Douglas-fir	10 674.3	10.5
Macrocarpa	1 183.6	1.2
Other pines	6 035.2	5.9
Larch	2 348.6	2.3
Other	1 065.0	1.0
Total	102 041.0	100.0

3. Capital, revenues and expenses.

Fixed capital is defined as the stock of durable goods such as buildings, plant machinery and equipment used in production (Bannock et al. 1978). Table 11 shows, by size class, the average book and replacement values for fixed capital in the Canterbury sawmill industry, along with the average depreciation on these items for the last calendar year. As several respondents were unsure of book and/or replacement values, these averages are based on a subset of each production class. Also, two mills in the smallest class and one in the second smallest were reported as "written off" (i.e. book value and depreciation equal zero). The large discrepancy between average book ($549,965) and average replacement ($2,263,095) values reflects this, and indicates the magnitude of the capital investment required to modernize the industry.

Attempts to collect revenue data for each final product met with little success; as such, revenue is reported as an aggregate figure incorporating all final products for each of the four production classes. Table 12 shows total revenue and the distribution of expenses for each production class and overall. Because of inter-industry transfers of goods and services (at least 3 mills in the smallest class operate on a contract basis for larger mills), some double counting of both costs and revenue is unavoidable. All sales figures are F.O.B. mill.

Labour expenses are based on 8-hour shifts, one shift per day, five days per week and fifty weeks per year. Table 13 shows the total number of employees (salaried and waged) giving rise to this expense, by production class. The industry reported 70 fewer employees overall than in 1984 (350 vs 420) but the corresponding total labour costs actually rose by more than $500,000 (derived from Department of Statistics 1984) during the same period, indicating the magnitude of the increases in labour costs over this period. Reported labour costs were generally 5 - 10 percent greater than those based on applicable award rates and agreed well with figures presented by the New Zealand Timber Industry Federation (1986).

The differences in average wood costs per cubic metre (weighted over all species) for each production class are highlighted in Table 14. Higher costs for the larger mills reflect the greater average hauling distances to these plants from Canterbury's forests. Most mills buy wood delivered on the mill skids, so no separate analysis of hauling costs has been performed. The low average wood costs shown for the smallest production class reflect the proximity of many of these mills to wood supplies, and are explained to some degree by the presence of a portable mill and two contract mills in this class, all with minimal direct wood costs. Despite this, wood costs are a major expense in each class, ranging from 24 to 58 percent of sales (average 30 percent) and 29 to 69 percent of total manufacturing costs (average 40 percent).

Other expenses include charges for materials and supplies, maintenance and repairs, contractor payments, etc. Fixed expenses refer to general and administrative charges which remain relatively constant regardless of production level. Finally, the "Residuals" row in Table 12 includes depreciation, taxes, other unallocated residuals and profits.

Table 11. Average book and replacement value and dep'n on fixed capital.

Class/Item	R	Avg B.V. ($)	Avg R.V. ($)	Avg Depreciation ($)
>10 000	2	3 000 000	10 500 000	135 000
5 001-10 000	4	562 400	2 460 000	30 355
2 500- 5 000	4	427 875	1 783 335	17 665
< 2 500	4	21 250	440 625	1 875
Total	14	549 965	2 263 095	25 845

Note: R is the number of respondents in each class

Table 12. Total revenue and expenses ($).

Item/Class	>10 000	5 000-10 000	2 500-5 000	<2 500	Total
Sales revenue	16 750 000	11 286 000	4 853 000	1 680 000	34 569 000
Labour expense	3 430 000	1 869 566	884 909	471 000	6 655 475
Wood expense	4 011 390	3 252 316	2 825 124	423 600	10 512 430
Power expense	220 000	145 000	52 500	32 100	449 600
Other expenses	1 750 000	999 046	107 500	45 000	2 901 546
Fixed expenses	4 500 000	1 763 000	206 500	94 500	6 564 000
Residuals	2 838 610	3 257 072	776 467	613 800	7 485 949

Table 13. Total labour.

Class	Person-years of employment
>10 000	165.0
5 001-10 000	100.0
2 500- 5 000	54.0
< 2 500	30.5
Total	349.5

Table 14. Average wood costs.

Class	Average wood cost ($/m^3)
>10 000	56.66
5 001-10 000	47.65
2 500- 5 000	58.60
< 2 500	19.43
Total	50.28

4. Markets and the Future.

The Canterbury sawmill industry exported 21 percent of its production in 1985-86, all to Australia via the port of Lyttleton. Large sawmills accounted for most of these exports, both in value and in volume (Table 15). Exports to Australia are expected to continue to be a mainstay for many Canterbury mills, with four companies having established sales offices across the Tasman. Nine of the mills have plans for substantial increases in production over the next ten years (Table 16), with all of the wood arising to be sent to overseas markets (primarily Australia). Although Australia was the only overseas market specifically referenced here, it is generally felt throughout the industry that other export markets need to be actively pursued and penetrated, particularly in light of the potential for a doubling of harvested volumes from Australia's own softwood plantation resource (consisting of 70 percent radiata pine) by the year 2000 (Gentle 1986).

Table 15. Volume and value of Canterbury wood exports.

Class/Item	Volume: m³	%	Value: $	%
>10 000	12 400	57.4	4 840 000	62.0
5 001-10 000	6 955	32.2	2 378 000	30.5
2 500- 5 000	1 712	7.9	433 000	5.5
< 2 500	540	2.5	160 000	2.0
Total	21 607	100.0	7 811 000	100.0

Table 16. Mills planning production increases within 10 years.

No. planning increases	Increase to: Domestic	Australia	Other
9	0	8	1

SUMMARY

This report has presented statistics collected from the Canterbury sawmill industry in 1986, along with a brief discussion of the region's past and present resource base. Many of the figures are unavailable from other sources and may thus prove valuable to sawmillers, planners and/or researchers. The data base, however, is only as good as the quality of response given by individual sawmills. Further work in this area may result in improved statistics and an updated report. The highlights of the report can be summarised as follows:

1. Resources.
   - Canterbury has 47 621 ha of exotic forest containing 7 645 000 m^3 of growing stock, 83 percent of which is radiata pine
   - the average age of Canterbury forests is 13 years, with 50 percent of its forests under 10 years of age
   - by 2010 sawlog production from State Forests alone should have increased four times from the current level of 72 500 m^3/an

2. Industry.
   - Canterbury's sawmill industry consisted of 21 firms in 1986, seven fewer than in 1984
   - output varied from 500 - 24 000 m^3/an, with the two largest mills accounting for roughly one-third of lumber production
   - Waimari District had the greatest concentration of mills (5), followed by Rangiora District (including Kaiapoi Borough) and Heathcote County (including Chch south) with 3 each

3. Production.
   - Canterbury mills produced 102 041 m^3 of sawn timber in 1985-86, as well as 23 400 m^3 of firewood and 31 979 m^3 of wood chips, operating on average at 82 percent of engineered capacity
   - 209 066 m^3 of logs were utilised in this production, with conversion factors ranging from 0.40 - 0.63 (mean=0.47)
   - framing grades were by far the major lumber product, making up 61 percent of sawn timber production
   - radiata pine constituted 79 percent of sawn timber production

4. Economic Impacts.

- average replacement (book) value for Canterbury mills is $2,263,095 ($549,965)
- gross sales of all forest products amounted to $34,569,000
- wood expenses made up 24 to 58 percent (average 30 percent) of sales and 29 to 69 percent (average 40 percent) of manufacturing costs in Canterbury sawmills
- the Canterbury sawmill industry provided 349.5 person years of employment in 1985-86, with a total direct payroll of $6,655,475
- exports of forest products contributed $7,811,000 in external income to the Canterbury economy
- exporting mills plan to increase sales to Australia within the next ten years, but realise the importance of finding and penetrating new export markets

ACKNOWLEDGEMENTS

The assistance of the Canterbury Timber Association and its sawmill members is gratefully acknowledged, as is the support of all mill managers who cooperated in this study. Thanks are also due to Mrs. Betty Huggins at the Department of Statistics and to Dr. Graham Whyte of the School of Forestry for their advice and guidance.

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SAWMILL SURVEY: DRAFT 1.0

Part 1. General Information

1. Mill name ______________

2. Registration number ______________

3. Location ______________

4. Mill type ______________

5. Capital value of plant and eqpt.($) ______________

6. Year of valuation ______________

7. Annual depreciation (plant and eqpt.$) (i) last year ______________

   (ii) avg., last 5 years ______________

   (iii)avg., last 10 years ______________

8. Current ROR on investment (%) ______________

   Desired ROR on investment (%) ______________

9. Briefly describe any planned alterations or expansions to your existing layout, including costs and production increases if available.

10. Do you wish to receive summarised survey results? **YES / NO**

SAWMILL SURVEY: DRAFT 1.0

Part 2. Resource/Processing Information

1. Total volume of logs sawn in last complete trading year (cu.m): ____________

2. Total sawntimber production in last complete trading year (cu.m): ____________

3. Annual rated capacity (cu.m) ____________

4. Complete the following table for last complete trading year:

Species utilized				
Volumes utilized (cu.m)				
Source(s) and average cost ($/cu.m)	1			
	2			
	3			
	4			
Grades produced (cu.m)				
(i) factory				
(ii) finishing				
(iii) dressing				
(iv) merchantable				
(v) #1 framing				
(vi) #2 framing				
(vii) box				
Other production (briefly describe)				
Residue prod'n (cu.m)				
(i) woodchips				
(ii) firewood				
(iii) other residues				

Note: for source(s) of raw materials, enter State Forest name or P(d) for private sources where d = average distance of that source from mill

: if no species breakdown of grades/residues produced is available, enter overall figures in column 1

: enter production figures only for residues actually utilised (i.e. those sold or re-used in plant)

: enter units if different from those given in table

SAWMILL SURVEY: DRAFT 1.0

Part 3. Cost Information

A. Labour
1. Number of persons engaged: ____________

2. Number of salaried positions: ____________

3. Number of waged positions: ____________

4. Total annual labour cost ($): ____________

B. Power
1. Total annual power cost ($): ____________

(Note if any cogeneration of electricity or heating of kilns is carried out by burning residues)

C. Transport and handling
1. Complete the following table for average transport costs, entering "R"(rail) or "T"(truck) adjacent to each cost given. Sources as in Part 2.4; markets as in Part 4.2. Enter units if costs are not in $/cu.m.

Source/Market	1	2	3	4
Source to mill				
Mill to market				

2. Volume of exports in last trading year (cu.m): ____________

3. Export ports used: (i) ____________

(ii) ____________

(iii) ____________

D. Other variable costs
1. Average annual cost for materials (other than logs), repairs and maintenance, etc. ($): ____________

E. Fixed costs
1. Average annual overheads ($): ____________

F. Other costs
1. List any costs of your operation not detailed above, including appropriate units.

SAWMILL SURVEY: DRAFT 1.0

Part 4. Revenue Information

1. Total annual sales volume for last complete trading year (if different from production figures given in Part 2.2-cu.m): ______________________

2. Complete the following table for each major market your product(s) serve(s) (cf. Part 3.C.1).

Market name				
Sales volume (%)				
(Specify each) Species/grades (%) (i)				
(ii)				
(iii)				
(iv)				
(v)				
(vi)				
Revenue ($/%) (i)				
(ii)				
(iii)				
(iv)				
(v)				
(vi)				

Note: Species/grades refers to the percentage of the production volumes reported in Part 2.4 allocated to each market. Likewise, revenue derived from each market can be broken down into that realised from each species/grade pair recognised above. If species/grade breakdowns on a market basis are unavailable, simply record the total sales volume percentages on the second line and record the total revenue obtained from each market.

3. Do you envision expanding your annual sales volume in the next five years? YES / NO Increase planned (%) ________

   ten years? YES / NO Increase planned (%) ________

4. If you answered yes to either of the above questions, what proportion of your increased sales volume will be allocated to existing markets? ______% Which one(s) (cf. Part 4.2) and in what proportions?

SAWMILL SURVEY: DRAFT 1.0

Part 4. Revenue Information

5. If your answer to Part 4.4 above was less than 100%, indicate which new markets you hope to penetrate and to what degree (i.e. what proportion of increased sales volume will be aimed at a particular market).

6. Please feel free to use the remaining space to expand on any of the issues raised previously or to identify issues which concern you as a sawmiller and businessman in Canterbury.

APPENDIX C

WOOD PROCESSING DATA BASE

The files making up the processing data base referred to in the text are contained in the IBM formatted diskette labelled "Appendix C" in the envelope on the inside back cover. The following table documents, for each file, name (including directory), length (in 60 line pages), and a general description of file contents. All files can be printed from any IBM compatible computer by using the DOS PRINT command, followed by the desired file name (with correct drive specification). The files should print on any printer capable of emulating an Epson FXQ printer (a standard feature on modern printers). Alternatively, files may be viewed on a terminal by entering the DOS TYPE command followed by the appropriate file specification. The text files in this appendix (CONSTRNT.PRN, OBJECTIV.PRN and IO.PRN) require 132 characters/line (13.2 inch standard dot matrix printer paper) to print correctly. The supplementary data tables in directories CO and OB (e.g. WOOD.PRN, NOMREV.PRN) have been formatted to print in compressed mode (20 cpi) in order to fit tables on a physical A4 page; these files can be difficult to view at a terminal as table rows can extend to two or three lines on the screen. All files may contain printer control sequences which should be ignored when viewed at a terminal.

Table C-1. Appendix C Files.

Name	Pages	Description
\CO\CONSTRNT.PRN	9	Documentation of constraint coefficients and right-hand side values
\CO\WOOD.PRN	2	Wood supply schedule worksheet (rhs's for local wood supply constraints)
\OB\OBJECTIV.PRN	11	Documentation of objective function cost and revenue coefficients
\OB\NOMREV.PRN	1	Nominal and discounted revenue tables,
\OB\DISCREV.PRN	1	all products and markets
\OB\NOMWOOD.PRN	1	Nominal and discounted woodcost tables,
\OB\DISCWOOD.PRN	1	all log types and forests
\OB\PCOST.PRN	1	Processing cost table (nominal/discount)
\OB\CDICOST.PRN	1	Capital cost table (nominal/discount)
\OB\SCOST.PRN	1	Storage cost table (nominal/discount)
\OB\SDREV.PRN	1	Shut-down proceeds table (nom./disc.)
\IO\IO.PRN	7	Input-output coefficients for 16 wood products (8 not included in the case study)

APPENDIX D

WPPM PROGRAMS AND SAMPLE OUTPUT

The WPPM programs and sample output referred to in the text are contained in the diskette labelled "Appendix D" in the envelope on the inside back cover. The following table documents, for each file, name (including directory), length (in 60 line pages), and a general description of file contents. All files can be printed from any IBM compatible computer by using the DOS PRINT command, followed by the appropriate file specification. Some of the files in this Appendix (as opposed to those in Appendix C) are relatively large, and may be examined more economically at a terminal using the DOS TYPE command.

Table D-1. Appendix D Files.

Name	Pages	Description
\PGMS\DATMAT.F77	40	DATMAT (matrix generator) listing
\PGMS\WPPM.SAS	1	SAS programs for invoking or restarting
\PGMS\RESTART.SAS	1	PROC LP
\PGMS\REPORT.SAS	10	Report writer program listing
\EXPL\RESTART.LOG	1	Sample log file from case study
\EXPL\RESTART.LIS	54	Sensitivity analysis and standard solution listing (condensed) from case study
\EXPL\VAR.LIS	1	Variable listing for case study problem
\EXPL\MATRIX.SPL	1	Sample observation from matrix generated by DATMAT
\EXPL\DATMAT.SPL	16	Partial DATMAT session from a small demonstration problem (file copied directly from terminal session)